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The Role of Transport Infrastructure in Regional Economic Development

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Summary:
The aim of the present dissertation is two-fold. Firstly, it tries to understand whether the economic effects of transport infrastructure provision exist and are significant enough to be accounted for when making policy decisions. A SCGE model for Norway (PINGO) is used for the empirical analysis. The main conclusion is that although provision of transport infrastructure by itself does not lead to economic growth, its positive welfare effects are quite significant in monetary terms and increasing over time if one takes into account future production growth. Secondly, the dissertation develops a generic SCGE model incorporating location decisions of households and firms, housing markets, different market imperfections and explicit representation of real transport network. The functionality of the proposed model is illustrated using a hypothetical example.

Sammendrag:
Denne doktorgradsavhandlingen er todelt. For det første analyseres økonomiske effekter av transportinfrastrukturutvikling ved bruk av en spatiell generell likevektsmodell (SGL) for Norge (PINGO). Konklusjonen fra den empiriske analysen er at selv om transportinfrastruktur ikke er nok for økonomisk utvikling, er velferdseffektene betydelige dersom man tar hensyn til framtidig produksjonsutvikling. For det andre utvikles en ny type SGL-modell som inkluderer husholdningenes og produsentenes lokaliseringsbeslutninger, boligmarkeder og forskjellige markedsimperfeksjoner, og der transportnettverket inngår. Modellen er implementert ved bruk av et hypotetisk datasett.

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Oslo, August 2003

Olga Ivanova

Summary:

The Role of Transport Infrastructure in Regional Economic Development

In the last decades increasing attention of the researchers have been paid to the spatial economic phenomena as well as to the spatial nature of economy. Such new developing fields of economics as regional and urban economics, economic geography etc have appeared leading to the development of new theories and models.

The influence of transport infrastructure on regional economic development and performance is one of many spatial economic phenomena attracting constant researchers' attention in the past years and is the theme of the present dissertation.

Although there exists a clear understanding among researchers that in theory transport infrastructure influence economy on both micro-, macro-, regional and network levels of performance, empirical evidence on this subject is quite ambiguous and researchers contradict each other in their conclusions about the magnitude of such economic effects.

The aim of the present dissertation is two-fold. Firstly, it tries to understand whether the economic effects of transport infrastructure provision exist and are significant enough to be accounted for while making policy decisions using Norway as an example of a country with well-developed transport infrastructure. The SCGE model for Norway (PINGO) developed in 2002 at TØI as a joint work between the candidate, Arild Vold and Viggo Jean-Hansen is used for the empirical analysis. The main conclusion from the performed empirical analysis is that although provision of transport infrastructure by itself does not lead to economic growth, its positive welfare effects calculated under the assumption of future economic growth are quite significant in monetary terms and increasing over time.

Secondly, the dissertation develops a generic SCGE model incorporating location decisions of households and firms, housing market, different market imperfections and explicit representation of real transport network. The developed model is able to capture the effects of infrastructure improvements at both micro-economic level, regional economic level and the level of real transport network and allows one to represent all major effects that infrastructure improvements may have on the economic performance of a region or a country. Functionality of the proposed model is illustrated using the hypothetical example.

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PINGO – A model for prediction of regional- and interregional freight transport – Version 1 with appendices. TØI report 578/2002.

Introduction

1. The spatial nature of economy

In the recent decades more and more attention is paid to the spatial nature of economy. Such important fields of contemporary economics as economic geography (Krugman, 1991), urban economics (Jacobs, 1984), regional economics and spatial environmental economics (Forsund, 1972) have been founded and are developing fast. Neglect of spatial dimension in economics in the past has led to the situation where a number of important economic phenomena is still not explained or investigated.

In order to perform the analysis of spatial phenomena there is a need in the new type of equilibrium models, accounting not only for spatial dimension but also for imperfect competition, increasing returns to scale and agglomeration effects. One of possible alternatives is the spatial general equilibrium modeling. This kind of models is still not widely used. The largest part of their applications lies in the field of regional economics. Spatial general equilibrium models represent economy as consisting of a number of regions situated in geographic space and connected with the help of transport infrastructure. These models have quite complicated mathematical formulation and it is just lately become possible to compute their solutions in reasonable amounts of time, thanks to the fast development of computer technologies and mathematical algorithms.

One of the spatial phenomena, which may be analyzed with the help of spatial general equilibrium model, is the role of transport infrastructure in regional economic development and an economy as a whole. A number of researchers have tackled this problem with the help of both empirical case studies and models. The most important results of their research and methods used are summarized as follows.

A number of studies performed in the developing countries have demonstrated the importance of transport infrastructure for an economic development in backward regions. Influence of the establishment of new transport links was quite strong according to the case studies performed by World Bank in India, Pakistan and Brazil (Creightney, 1993 and

Lall et al, 2001). Strong dependency upon the quality of infrastructure and economic development in these countries exists, since a transport link unlocks the resources of backward regions such as land and labor promoting their efficient utilization.

The role of infrastructure in well-developed counties is ambiguous. On one hand, it is difficult to challenge a fundamental assumption that economic growth, the need for mobility of economic resources and goods and the need to invest to facilitate this mobility go hand in hand. On the other hand, there exists no straight evidence that it is improved infrastructure that facilitates economic growth and not the opposite. What is interesting for the researchers is not only the question of whether infrastructural improvements have positive effect on the economic development, but mostly the size of this effect.

Relationship between the provision of transport infrastructure and economic growth is rather complicated one and may be traced at micro, macro and regional levels of the analysis.

Transport as one factor in the production of goods and services, represents a cost to individual firms. According to the traditional economic logic an infrastructure improvement reducing costs of transportation (through lower travel times or vehicle operating costs) enables firms to sell their goods more cheaply, which facilitates demand and hence production of the firms.

The importance attached by firms to infrastructural improvements has been questioned by a number of researchers. Some ague that small transport costs reductions, which are usually associated with infrastructural improvements in the developed countries, will be of limited benefit to the individual firms. Others have challenged the possibility that transport cost reduction will be translated into increased production capacity by the individual firms.

Thus Parkinson (1981) has pointed out that transport costs are a very small proportion of the total costs (5-6%) and hence, given rather small reduction of them, arising for example from establishment of a new road in the region, infrastructure improvement is unlikely to affect the output of an individual firm. Other studies make somewhat different picture. Ernst and Young consultancy (1996) made clear that the proportion of transport cost in the total costs of a firm varies significantly from sector to sector. For some firms they may present a major item. Figures compiled by Diamond and

Spence (1989) indicate that transport costs accounted for 2.6% of total operating costs in motor vehicle part production, 7.7% for pharmaceutical and 12% for wholesale distribution. In other sectors, the figures can be significantly higher. Potential improvements of transport infrastructure may be than of considerable benefit.

While there remains debate about the scale of direct benefits to firms from the infrastructural improvements, attention of the researchers have also been focused on the potential indirect micro-benefits. According to Ernst and Young consultancy (1996), over 20% of firms have reported that changes in infrastructure have led to benefits in the form of reduced inventory costs (through reorganization and centralization of distribution operations), their ability to access new markets and increased size of the available labor areas.

Some researches ague, however, that any direct or indirect benefits to individual firms from the infrastructural improvements are soon lost due to increased pollution and congestion, since additional traffic is generated. In some cases these benefits may even become negative.

A key aspect of the debate about the relationship between transport infrastructure and an economy are the claims of the impact that a transport project has on the development of a local area or a region. In this context infrastructural improvements are seen as a way to remove barriers to trade with other regions. Removing trade barriers by improving a transport link is argued to help use regional resources such as land and labor more efficiently. Moreover poor transport links between regions may protect uncompetitive firms and give them significant power within a region. Infrastructural improvements thus facilitate competition between the firms and improve efficiency.

However, there are alternative views about the impact of infrastructural improvements on an economic performance of a region. First, researchers point out that better infrastructure by itself is highly unlikely to stimulate economic activity. It is recognized that while infrastructural improvements may be necessary, they are rarely, if ever, a sufficient condition for economic development. Parkinson (1981) notes that according to the empirical evidence, areas with low levels of development seldom lack just good accessibility, they have disadvantages other than or in addition to lack of good transport infrastructure, such as lack of sites or skilled labor. In this respect it is essential for the regulators to supplement investments in infrastructure with other policy measures.

Infrastructural improvements can also harm a regional economy, by exposing regional firms to the competition from the strong rivals outside the region. Since the infrastructure improvement is similar to removing a trade barrier there may be winners and losers among regions depending upon the structure of their economies. A report on completing the European Single Market (Emerson, 1998), which aims to reduce trade barriers within the EU, indicated that, while overall EU productivity would rise, much of this came from a rationalization of industry that would imply the end of production in individual sectors in some counties. Even if the infrastructure improvement leads to positive effects for all the regions involved it is certain that the size of these effects would be different.

The debate about the relationship between transport infrastructure and the economy focuses not only on the impacts on individual firms or regions, but also on the economy as a whole. The close correlation between economic growth and increased mobility and since 1945, the correlation in particular between road traffic growth and economic growth is seen as evidence of a close link between transport infrastructure and the economy. But this does not help to define the direction of the cause-effect relationship. One cannot be sure whether increased mobility and developed transport infrastructure is the sign of good economic performance facilitated by other factors or whether infrastructural improvements themselves facilitate economic growth. Nevertheless, researches point to the historical contribution of infrastructural improvements to economic development. This is particularly true for the case of developing countries, where the transition from a fragmented communication system to even a poorly developed network is of great importance (Owen, 1987; Hilling, 1996). In this sense, the complete absence of a well-developed transport infrastructure acts as a serious constraint to growth. It helps explain why up to 40% of World Bank loans have been used on transport infrastructure projects (Hilling, 1996).

The concept of globalization is rather useful when one thinks about the role of transport infrastructure. Generally speaking, globalization is about the changing costs of economic interactions across distance and the effects of these changes on the geographical distribution of economic activity (Crafts and Venables, 2001).Transport infrastructure improvements clearly have certain effect upon the choice of geographical locations by economic agents such as firms and households inside a region or a country.

For a country with well-developed transport infrastructure, the question arises as to whether further improvements can have any significant benefits. McKinnon (1995) takes the view that new road construction projects are likely to make smaller contribution to the economic development than in the past, partly because much of the network related benefits of infrastructure have been already realized. Aschauer (1989) , however, argues that public investment in infrastructure have significant positive effect on GDP, since they increase firm's profitability or rate of return to private capital. Firms then respond by increased capital investments, in turn leading to higher labor productivity and output facilitating further investments.

Researchers have used a number of different methods in order to analyze the role of transport infrastructure in regional development. A number of studies described in Forkenbrock and Weisbrod (2001) used quasi-experimental control group analysis and macroeconomic indicators such as population, employment, income per capita and so on. These studies perform analysis on the firm level by interviewing firms at the region under consideration in order to find out the relationship and also use a number of regional economic indicators to support the study. It is remarkable that the results of these studies appear to differ from one another: some authors find a positive relationship and others a negative or inconclusive one. Thus controlled micro experimentations do not guarantee satisfactory results. A disadvantage of micro case studies of the above type is that they focus only on productivity improvements for firms directly affected by infrastructural improvements. Indirect effects on other economic actors such as agglomeration effects (Krugman, 1991), for example, are usually not taken into account.

Another type of approach used in regional studies is the production function approach. The approach consists of estimation of production functions for different types of sectors in a region as functions of different input factors including transport infrastructure. One evident drawback of the approach is that it does not allow accounting for the network properties of transport infrastructure. Most of the work on the contribution of infrastructure to productivity has been carried out on the national level. For example, Aschauer(1989) found for US time series data an output elasticity of infrastructure of no less than 0.4 (that is, one extra unit of infrastructure leads to 40 percent increase in productivity). However, in more recent research much lower coefficients often found (Munnell, 1993).

2. Spatial General Equilibrium approach

A Spatial General Equilibrium (SGE) approach has been most successive in capturing various impacts of infrastructural improvements on regional economic development. The theoretical basis for these models is the notion of Walrasian equilibrium. Hence, they are capable of representing interrelations between various agents in an economy in a consistent and simple manner. SGE models are used traditionally to represent an economy as consisting of a number of geographical regions that are connected by trade/transportation flows between them and adopt Armington's assumption to realize multiregional cross-hauling trade. Since it usually takes several years for investment in transport infrastructure to become operational, supply of the infrastructure cannot be readily adjusted in the short-term and for this reason transport infrastructure is thought of as an endowment of primary resource in an economic system in the context of SGE modeling.

SGE models used in the analysis differ a lot with respect to representations of transport infrastructure and transport sector. In general they may be divided into two wide groups: country-level SGE models and city-level SGE models.

The first group of models does not have implicit representation of a transport network and represents a whole country as divided into a number of regions. The models consider just freight transportation between regions and do not account for congestion effects. There are costs of transportation between each pair of regions, which account for differences in regional prices of consumption and intermediate goods. In some first type models such as van den Berg (1996), Roson (1996), Hussain (1996) and Miyagi (1996) transportation services are produced by a transport sector at prices (transport costs), which are fixed outside the models. By changing transport costs one may account for possible changes in transport infrastructure and see what economic consequences they lead to. The model by Brøcker (1998) is a bit different and uses the so called "iceberg concept" of transport costs. According to this concept a certain proportion of transported commodity itself is used during transportation so that improvements of transport infrastructure lead to reductions of these proportions.

The country-level SGE models may be used for the analysis of economic impacts of large-scale national infrastructural projects, which influence production and consumption patterns on the macro-level, but they would not capture such effects as relocation of households, changes in land use and passenger transport patterns.

The second group of models describes a city or a region and has an implicit representation of transport network. These kinds of models concentrate on passenger transportation and land use inside a region. They consider location decisions of firms and households inside a region or a city as well as agglomeration effects. A city or a region is divided into a number of zones, where production or consumption activities are located. A specific transport cost function is associated with each pair of zones, which usually allows one to account for congestion on the roads. Usually there is made no distinction between traveling by car and by public transport for households' trips and freight transport is not represented in this type of models.

The models by Banister (2000), Anas (1999), Mun (1997), Sasaki (1992) and Mackett (1992) are examples of city-level SGE models. The model by Banister was developed in order to investigate the role of transport infrastructure development in local economic growth and focuses on accessibility of locations inside a region. Infrastructure influences decisions of agents through an agglomeration effect and willingness of households to supply labor, which depends upon home-to-work travel times. The representation of production and utility functions are rather simple and transport network consists of zones and time cost functions between them. Other models are rather similar to this one but concentrate more on land-use and job-dispersion.

The city-level SGE models can capture the influence of improved transport infrastructure on production, consumption patterns and their location inside a region as well as on land use and job-dispersion. The drawback of these models is incomplete representation of transport infrastructure as well as the absence of freight and public transport.

Although both types of SGE models are suitable for analyzing the role of transport infrastructure in regional economic development, there exists the possibility to combine their strong sides in one synthetic model in order to account better for various effects of infrastructure improvements on a regional economy. An implicit representation of transport infrastructure as consisting of nodes and transport links connecting them would allow for analyzing possible effects and welfare gains of a particular infrastructural project and changes in the use of transport infrastructure as given by new transport network equilibrium.

The idea of integrating SGE and real transport equilibrium models was developed by Friesz (1996) but has not been implemented in any simulation or empirical study. Friesz has demonstrated the possibility to represent both SGE and real network equilibrium models in the form of Mixed Complementary Problems (MCP), which allows one to compute their simultaneous equilibrium. Such formulation helps to escape inevitable iterative procedure used when they are formulated in the form of two separate mathematical problems (Roson, 1996) and hence significantly reduces solution time.

In order to be able to capture the effects of infrastructure improvements at both micro-economic level, regional economic level and the level of real transport network a SCGE model incorporating location decisions of households and firms, equilibrium on housing market, market imperfections and real transport network equilibrium should be developed. Such model allows one to represent all major effects that infrastructure improvements may have on the economic performance of a region or a country. Hence, the model allows one to understand the role of infrastructure in regional economic development in the best way.

It has been argued a lot in the literature that the present method of estimating welfare benefits of a particular infrastructure project by looking just at the reduction of transport costs does not capture all effects of infrastructure improvements and hence the estimated welfare benefits may be significantly higher in reality. Even though a number of case studies have looked upon other effect of infrastructure investments for a particular region, there exists no systematic modeling approach allowing for performing such welfare benefit analysis as a routine procedure.

The SCGE model incorporating real transport network representation allows one to analyze the welfare benefits of a particular new infrastructure link in the most complete manner using data available in most of the countries. Solution time for such a model is rather low, which gives a transport ministry the possibility to analyze significant number of separate infrastructure investment projects and combinations of them and hence to choose the optimal allocation of infrastructure investments, given the specific economic structure and transport network of a region or a country.

Governments have different options with respect to transport infrastructure investment decisions. First, they may invest in infrastructure as a response to serious bottlenecks taking place due to expansion of an economy. This is a passive strategy: investments in transport infrastructure follow the expansion of production and hence increase in transport flows. Another option is that governments use transport infrastructure to stimulate national economy and increased production or at least make it compatible with future economic growth. This is an active strategy: investments are made beforehand and there is no shortage of infrastructure in the future.

The generic SCGE model incorporating real transport network representation provides governments with the possibility to forecast future transport flows given the forecasts for future production growth rates in a region or a country. Hence, it represents a useful tool for understanding the magnitude and location of future needs in transport infrastructure and may help governments to perform an active strategy with respect to transport infrastructure provision.

3. Contents of the present dissertation

The present dissertation attempts to fill some of the gaps in regional economics and develops the generic SCGE model incorporating location decisions of households and firms, equilibrium on the housing market, market imperfections and real transport network equilibrium. It consists of the following three chapters representing development of the idea that supplement each other by considering different levels and aspects of the problem. The dissertation consists of three chapters; contents of and relations between those are described as follows.

Ch. 1 provides clear empirical evidence of the importance of transport infrastructure provision for future development of an economy. Empirical analysis is performed using the Spatial Computable General Equilibrium (SCGE) model for Norway PINGO (Ivanova et al, 2002) for the package of infrastructure investment projects for the period 2006-2022, proposed by the Norwegian Ministry of Transport. The package consists of a number of infrastructure projects to be performed each year from 2006 up to 2022 that are spread all over the country with slightly more projects in South-Vest industrial area and Oslo geographical area. Analysis is performed using the forecasted annual growth rates of production, export and import, provided by the Norwegian macro-model MSG-6 (Holmøy, 1992) and transport costs derived using the national real freight network equilibrium model NEMO (Vold et al, 2002).

The main claim of Ch. 1 is that although provision of infrastructure by itself does not lead to economic growth in well-developed economies, the welfare gains of infrastructure provision are significantly high if one accounts for the future economic growth. Moreover these welfare gains are higher the higher the future economic growth and are increasing over time. Transport infrastructure hence may be interpreted as a crucial economic resource such as land or labor, which is necessary for normal functioning of any economy and especially for sustainable economic growth. The lack of this economic resource leads to inevitable welfare loss.

The SCGE model used in Ch. 1 proved to be useful instrument in calculating the welfare benefits of an infrastructure investment package. The model captures most micro-economic effects of transport infrastructure improvements such as reduction in the production costs to individual businesses as the result of decreased transport costs. It also captures partly some regional effects for example changes in trade patterns between the regions. However, a large part of important regional effects is not captured by the model. Such important issues as the influence of changes in transport infrastructure upon location of households and firms as well as upon the structure of markets are not represented at all, due to the particular assumptions of the model. Since the model is rather aggregated one, that is representing the whole country as consisting of a restricted number of regions, only significantly large infrastructure improvements and investment packages may be analyzed with the model. Hence, there is a need for further modeling developments in order for all the mentioned issues to be accounted for.

In Ch. 2 the first aim is to present a new formulation of simultaneous network equilibrium for both car and public transport in the form of Mixed Complementarity Problem, incorporates it into bi-level programming framework and implements it for Oslo/Akershus region of Norway. The second aim is to investigate the role, which functional form of social welfare measure plays in optimal infrastructure investment choice using Oslo/Akershus case-studio.

The model presented in Ch. 2 has the structure of bi-level programming or leader-follower game (Macrotte, 1986), where a transport ministry is the leader and citizens are the followers. The lower level of bi-level programming represents the changes in traveling behavior of citizens for a given allocation of investments. The upper level represents the choice of investments allocation by a transport ministry in order to maximize social welfare.

The travel behavior of citizens is usually represented in the form of network equilibrium model. In most contemporary applications network equilibria for car and public transport networks are formulated as two separate equilibrium models, so that their simultaneous equilibrium is found by using an iterative procedure.

The model presented in Ch. 2 provides a new formulation of simultaneous network equilibrium for car and public transport in the form of single Mixed Complementarity Problem (MCP), which allows one to skip iterative procedure and hence to save considerable amounts time. Moreover, this formulation gives one a possibility to integrate the network equilibrium into bi-level programming framework using such modeling systems as GAMS, Mathematica and Matlab. Hence, a transport ministry is able to consider all combinations of possible infrastructure investments and hence increase probability that the chosen variant is close to the ultimate optimum. The formulation of network equilibrium in the MCP form is also easily integrated with Spatial General Equilibrium models and land-use models, since they are formulated in the same functional form.

The model presented in Ch. 2 is the network equilibrium model and hence just incorporates effects, that transport infrastructure improvements have on the level of network performance i.e. their direct effects. The welfare benefits calculated with the help of presented model do not capture any of the indirect effects, which infrastructure improvements have on the performance of a city. It does not account for any economic effects of new infrastructure as well as for its effects upon freight transportation inside a city as well as upon locations of households and firms. In order to give more complete picture it is necessary to connect the presented model with the Spatial Computable General Equilibrium (SCGE) model of a city as well as with a freight network equilibrium model.

The model developed in Ch. 3 provides a link between the two models used for analysis in previous chapters and hence combines their strengths. Ch. 3 develops the modeling tools of previous chapters further in order to be able to represent the effects of infrastructure improvements upon locations of firms and households as well as upon the levels of competition at markets, in particular at the market for transport services.

The aim of Ch. 3 is to develop and present a regional Spatial Computable General Equilibrium (SCGE) model with explicit transport network and congestion on it, endogenously determined employment and production locations as well as representation of market power of firms and transport modes. Locations of firms and households' choices of employment locations are interrelated in the model and depend upon the structure and capacity of transport network. The second aim of Ch. 3 is to solve the constructed model using a hypothetical example in order to investigate the role of transport infrastructure in regional economic development.

Development of the model presented in Ch. 3 is motivated by the fact that previously developed general equilibrium models, incorporating influence of transport infrastructure on regional performance, such as the models of Anas and Xu (1999), Brøcker (1998), Hussain (1996), Roson (1996) and Lederer (1989) do not account for all micro-level and regional level effects of infrastructure improvements. In some of them transport infrastructure is represented by exogenously given travel costs. Others do not consider allocation of employment and economic activities in a region. None of the models accounts for market imperfections such as market power of firms and transport modes and has explicit representation of real transport network, which are important parts of the model presented in the paper. Due to these missing parts previous analysis of the role of transport infrastructure in regional economic development cannot be considered to be complete and there is a need for the new type of regional model.

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Chapter 1

Evaluation of infrastructure welfare benefits in the Spatial Computable General Equilibrium (SCGE) framework

Although there exists a theoretical understanding among researchers that stable growth in well-developed economies is related to a provision of transport infrastructure through a number of channels on micro, regional and macro levels, no clear empirical evidence of this have been provided so far. The present paper uses Spatial Computable General Equilibrium (SCGE) model of Norway in order to derive welfare gains of infrastructure provision and demonstrates that they are quite significant under the assumption of future production growth in the country. It also argues that transport infrastructure may be interpreted as a scant economic resource, which is necessary for normal functioning of an economy and especially for sustainable economic growth.

1. Introduction

In the developing economies, infrastructure in general and transport infrastructure in particular is seen as an essential prerequisite for economic growth. A number of influential case studies performed by World Bank in India, Pakistan and Brazil (Creightney, 1993 and Lall et al, 2001) have demonstrated the strong dependency of economic development in these countries upon the quality of transport infrastructure, which unlocks the resources of backwards regions such as land and labor for their efficient utilization.

In well-developed economies, where the role of infrastructure is not that large any more, the picture is quite different and the role of infrastructure is quite ambiguous. There is a theoretical understanding among researchers that economic development is in general related to provision of infrastructure through a number of channels on the micro, regional and macro levels, but no clear empirical evidence of this phenomenon has been provided.

The aim of present paper is to fill this gap and present a clear empirical evidence of the importance of transport infrastructure provision for future development of an economy. Empirical analysis is performed using the Spatial Computable General Equilibrium (SCGE) model for Norway (Ivanova et al, 2002) to estimate welfare benefits of the package of infrastructure investment projects for the period 2006-2022, proposed by the Norwegian Ministry of Transport. The package consists of a number of infrastructure projects to be performed each year from 2006 up to 2022 that are spread all over the country with slightly more projects in South-Vest industrial area and Oslo geographical area. Analysis is performed using the forecasted annual growth rates of production, export and import, provided by the Norwegian macro-model MSG-6 (Holmøy, 1992).

The main claim of the paper is that although provision of infrastructure by itself does not lead to economic growth in well-developed economies, the welfare gains of infrastructure provision are rather significant if one accounts for future economic growth. Moreover these welfare gains are higher the higher is the future economic growth and increasing over time. Transport infrastructure may be interpreted as a crucial economic resource such as land or labor, which is necessary for normal functioning of any economy and especially for sustainable economic growth. The lack of this economic resource leads to inevitable welfare loss.

Theoretically speaking, an efficient transport network is vital for a strong economy – locally, regionally and nationally – by providing high quality access to labor, suppliers and customers. Economic growth, production, consumption, the need for mobility of economic resources and goods and the need to invest to facilitate this mobility go hand in hand. The role of transport infrastructure for economic growth may be traced at micro, macro and regional levels of analysis.

At micro level, being one of the factors of production of goods and services transport represents costs to individual businesses and hence reduction in costs of transportation would enable them to increase production volumes and reduce prices. At macro level transport infrastructure investments as any type of investments facilitate higher production and employment in an economy and also facilitate other types of investments.

The impacts of transport infrastructure investments at regional level are the most complicated ones and are similar to those of removing trade barriers between regions. Removing such barriers may help to use regional resources such as land and labor more efficiently as well as to facilitate more competition on regional commodity markets. Increased competition may have ambiguous effects on regional economy, so that some regions will gain from improvement of transport infrastructure, while other regions may suffer from it.

Given the scarcity of public funds, governments are concerned to invest in transport infrastructure in the most efficient way. This requires governments or planners to understand future needs of the economy in infrastructure as well as the economic impacts of possible packages of infrastructure projects. It is important that the new investments are canalized to paths, where capacity of the transport network is too low to meet future demands for transportation and that of possible packages of infrastructure projects the most efficient one is picked up. The present paper demonstrates capabilities of such a tool as SCGE model to solve these problems, i.e. to predict future transport flows in an economy and hence to find possible future bottle-necks as well as to estimate welfare benefits of any given infrastructure investment package.

The paper is organized as follows. In Section 2 the SCGE model for Norway used in the empirical analysis is described. In Section 3 the welfare benefits of infrastructure projects package proposed by the Norwegian Ministry of Transport is calculated with and without taking into account the future economic growth. In Section 4 there demonstrated the possibility of the SCGE model to predict future transport flows between the regions. Section 5 concludes the paper.

2. Description of the SCGE model used in the analysis

SCGE model of Norway (PINGO) was developed at the Norwegian Institute of Transport Economics in 2001 and used for construction of the national transport plan. The Norwegian Ministry of Transport has financed its development and implementation. Complete description of the model may be found in Appendix to this paper.

Theoretical basis of the model is the Walrasian equilibrium in perfectly competitive economy. Economic activities in the Walrasian equilibrium are driven by consumers' endowments of production factors. By definition an economy is in equilibrium if and only if all endowments are utilized and markets for all commodities and factors of production clear.

Development of PINGO was based on the models proposed by Hussain (1996) and Brøker (1998). Both of the models are traditional SCGE ones and apply the Armington's assumption to realize interregional trade, while differ with respect to representations of transport sector and transport costs. PINGO in its present formulation is similar to the Hussain's model and incorporates an explicit representation of transport sector and transport costs.

PINGO represents the Norwegian economy as consisting of 19 domestic regions corresponding to the municipalities of Norway and one foreign region representing the rest of the world. Each domestic region represented in the model shelters a number of economic agents such as different production sectors each producing a certain number of commodities, one investment sector producing physical capital, one service sector producing both public and private services, transport agents and one representative household. Except for regional economic agents, the following macro-economic agents operating at the country level are represented in PINGO: one transport sector, one export sector, one import sector and the government. Export and import activities are performed under the assumption of small open economy i.e. import and export prices are considered as given in the model.

The following types of production sectors are operating in each domestic region of the model: (01) food production, (02) fisheries, (03) timber, wood ware, paper and cardboard, (04) production of masses, (05) hardware production, (06) chemical industries, (07) production of metals and metal products, (08) bulk production and (09) high value products. The production sectors use labor, physical capital and all types of commodities in the economy in order to produce the following output goods: (01) food, (02) fish, (03) thermo, (04) vehicles/machinery, (05) general cargo, (06) timber and wood ware, (07) coal, sand and gravel, (08) chemical products, (09) metals and ore, (10) bulk commodities (liquid). Each sector may produce several or all of these goods according to its CES production function. Investment and service sectors also use labor, physical capital and all types of commodities as inputs to their production but produce just physical capital or services respectively, according to their CES production functions.

Interregional trade in PINGO is performed according to the so-called "pooling concept". According to this concept, all commodities of the same type, produced in various regions and transported to a specific one for intermediate or final use, are first merged into a regional pool of this commodity, from where they are delivered to intermediate or final users in the region. Hence, conceptually there is a distinction between a good produced in the region and the same type of good transported to the region. Moreover there is a distinction between producer and consumer prices of any particular commodity.

Transport agents operating in each region of the model represent the pools of commodities in it. Each regional transport agent corresponds to a particular type of commodity so that there are in total 10 transport agents operating in each region. A transport agent is responsible for transporting its particular commodity from all regions of Norway using transport services and merging them into a regional pool according to specific production technology. Production functions of transport agents are of CES functional form, where the transport services are used in fixed proportions to the transported amounts of commodities and there is a high degree of substitutability between commodities of the same type produced in different regions. Transport agents may be interpreted both as wholesales and as an instrument representing equilibrium of a specific commodity on regional markets and allowing for deriving its equilibrium price.

Population of Norway is represented by one representative household per each region of the model. The representative households use their endowments of labor in order to consume commodities in a way that maximizes their utility functions. Utility functions of the households have CES functional form and differ between the regions of Norway.

In PINGO there is made no distinction between transportation services produced by professional carriers and by production firms themselves. Each transportation service consists of transporting one unit of a particular good between a particular pair of regions. All transportation services in the economy are produced by the national transport sector using domestic labor and commodities from all regions of Norway in its production process. Production function of the transport sector has CES functional form. Prices of all transportation services are exogenously fixed in the model and are equal to the transportation costs derived from the national real freight network equilibrium model NEMO (Vold et al, 2002).

PINGO has been calibrated using the Social Accounting Matrix (SAM) for Norway for the year 1998 and the transport costs derived from the national real freight network equilibrium model NEMO for the same year. Elasticity coefficients of the production and utility functions yet have not been estimated and in the first version of the model all production and utility functions are assumed to be of Cobb-Douglas functional form.

PINGO is formulated in the form of SCGE model and implemented using GAMS/MPSGE programming framework. GAMS/MPSGE allows one to compute equilibrium prices and quantities, when the model is properly specified in terms of production functions, utility function and endowments. In GAMS/MPSGE programming system utility and production functions are restricted to the Nested Constant Elasticity of Substitution (NCES) family, moreover utility functions are quasi-homothetic and production functions exhibit constant returns to scale.

The SCGE model of Norway (PINGO) and the national real freight network equilibrium model (NEMO) compose the united modeling framework. Any changes in transport infrastructure and other factors influencing transport costs are converted into the changes in transport costs using NEMO and are used as input to PINGO for further economic and welfare analysis. PINGO in its turn derives growth rates of transport flows between the regions of Norway based on forecasts of growth rates of production, import and export in the economy as well as the levels of transport costs. The growth rates of transport flows provided by PINGO are used as input to NEMO for further analysis of changes in freight transport flows on the particular links of real network. Except for growth rates of transport flows, PINGO may also derive growth rates of consumption in the regions as well as growth rates of inputs to the production sectors.

3. Evaluation of welfare benefits associated with future extension of transport infrastructure

3.1. Description of the scenario of future economic performance and infrastructure extension

The SCGE model of Norway used in the analysis is purely static one and is calibrated using Social Accounting Matrix (SAM) for the base year 1998, hence, it cannot simulate economic growth and technological progress. The macro-economic model of Norway MSG-6 (Holmøy, 1992) is used in order to get future annual growth rates of production, export and import for each of the 10 commodity groups used in PINGO plus growth rate for the production of services (11) and growth rate for the production of physical capital (12). Annual growth rates of production, export and import for the periods 1999-2010 and 2010-2022 received from the macro-economic model for Norway MSG-6 (Holmøy, 1992) are represented in Tables 1, 2 and 3 respectively.

Table 1. Annual growth rates of production for the commodity groups in PINGO

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12
1999-2010	0.0203	0.0351	0.0163	0.0019	0.011	0.0034	0.001	0.0198	0.0086	0.0046	-0.0029	0.00186
2010-2022	0.0106	0.0233	0.0115	-0.0018	0.0041	0.004	-0.0013	0.009	0.0081	-0.0319	-0.0188	0.0125

Table 2. Annual growth rates of export for the commodity groups in PINGO

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
1999-2010	0.0628	0.0509	0.0615	0.0419	0.0135	-0.0026	-0.0062	0.028	0.0129	0.0058
2010-2022	0.0151	0.0295	0.0325	0.0052	-0.0001	-0.0056	-0.00162	0.0102	0.0109	-0.0241

Table 3. Annual growth rates of import for the commodity groups in PINGO

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
1999-2010	0.0038	0.0193	0.0153	0.0142	0.0141	0.0349	0.013	0.0163	0.0135	0.0218
2010-2022	-0.0031	0.0144	0.0153	0.0182	0.0132	0.0233	0.0124	0.0148	-0.0006	0.0316

These growth rates are used as inputs to PINGO and allow for deriving annual growth rates of consumption, indirect utilities of representative households (one per each region) as well as annual growth rates of transport flows of each commodity group between all pairs of regions.

The Norwegian Ministry of Transport has planned a number of infrastructure projects to be performed each year from 2006 up to 2022 that are spread all over the country with slightly more projects in South-Vest industrial area and in Oslo geographic area. Transport costs, accounting for future changes in transport infrastructure, have been calculated for years 2006, 2012 and 2020 with the help of national real network model NEMO. On average, the reduction in transport costs due to newly build infrastructure is 1% in 2006, 1.2% in 2012 and 1.5% in 2020. Such small changes are due to the fact that only those projects, which are already planned and documented, have been included into the analysis. Yearly changes of transport costs allow for the representation of infrastructure development in PINGO and hence for deriving its welfare benefits and effects on economic performance of the regions.

3.2. Welfare benefit analysis

In the developed countries like Norway, with elaborated transport infrastructure, construction of new transport links alone does not lead to large welfare benefits or effects on economic performance, as it would be in the developing countries. It is rather the lack of necessary infrastructure improvements under the condition of economic growth that may cause troubles and result in significant losses of welfare. In order to test this hypothesis let us first consider how the infrastructure improvements alone influence economic performance of the country, by making the assumption that there is no exogenously given growth in production, export or import, the only growth is induced by the reduction of transport costs.

By using the transport costs for 2006 as input to PINGO, there have been received an increase of 359.07 hundred thousands NOK in the total indirect utility of households, that is due to an increase of 1845.64 hundred thousands NOK in the total consumption of households. These values are rather insignificant with respect to the base year figures and constitute just 0.058% and 0.062% of the base year total indirect utility and total consumption respectively. Increase in total transport flow and hence in total production in the economy is 0.056% that corresponds to 71.54 hundred thousands tons of goods. The effect of 1% decrease in transport costs on the economic performance of Norway is nearly insignificant. If one considers only the presented results it is possible to conclude that infrastructure improvements do not play any role in the economies of developed countries and hence there is no sense in further improvement of transport infrastructure. Let us now consider how the role of new infrastructure and its welfare benefits change as one introduces future economic growth.

In order to derive relative changes in indirect utilities, consumption and transport flows arising due to infrastructure development i.e. reduction of transport costs, there have been considered the following two scenarios: one without infrastructure improvements and one with them. Both scenarios include annual economic growth rates as given by Tables 1-3. In order to simulate the economic growth path, PINGO have been solved for each year of the period 1999-2022 and SAM matrix has been updated after each year in order to account for changes in consumption and transport patterns. Afterwards the growth rates of consumption, indirect utilities and transport flows that are due to infrastructure improvements have been derived using the respective values from two scenarios. The growth rates have been transformed into monetary units by multiplying them with monetary values for the scenario without infrastructure improvements. Resulting relative changes of total indirect utility and total transport flows in percent and in monetary units are represented at Figures 1-4.

Welfare gains of infrastructure extension are significantly higher when one accounts for economic growth and their value increases over time (Figure 1). Welfare gains in monetary units are enough to cover rather large investment costs (Figure 2). The difference between welfare benefits in 2010 and 2006 is higher then the difference between welfare benefits in 2012 and 2010, which is explained by the change in pattern of economic performance in 2010. According to the predictions of national macro-model, starting from 2010 economic growth of the Norwegian economy will slow down. Hence, the growth rates of production, export and import are reduced for most of commodity groups. One may conclude that the higher is the future economic growth the large are the welfare gains of transport infrastructure improvements and they rapidly increase over time. Transport infrastructure may be interpreted as a crucial economic resource such as land or labor, which is necessary for normal functioning of any economy and especially for sustainable economic growth. The lack of this economic resource leads to inevitable welfare loss.

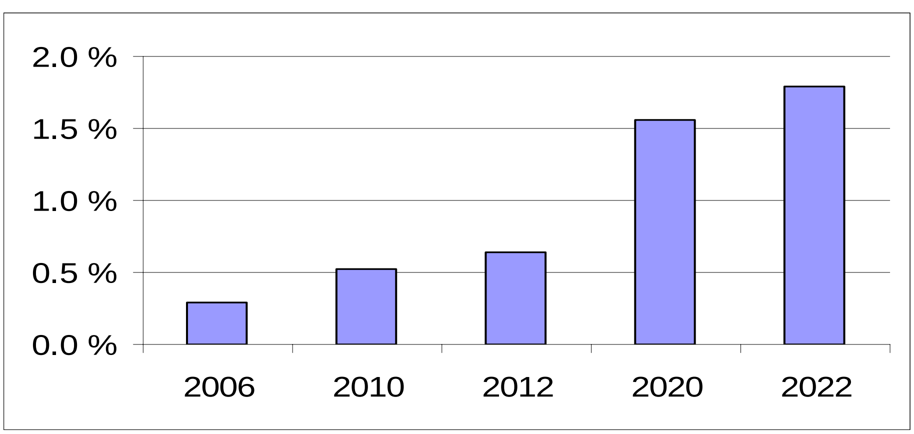

Figure 1. Relative changes in total indirect utility for years 2006-2022 in percent

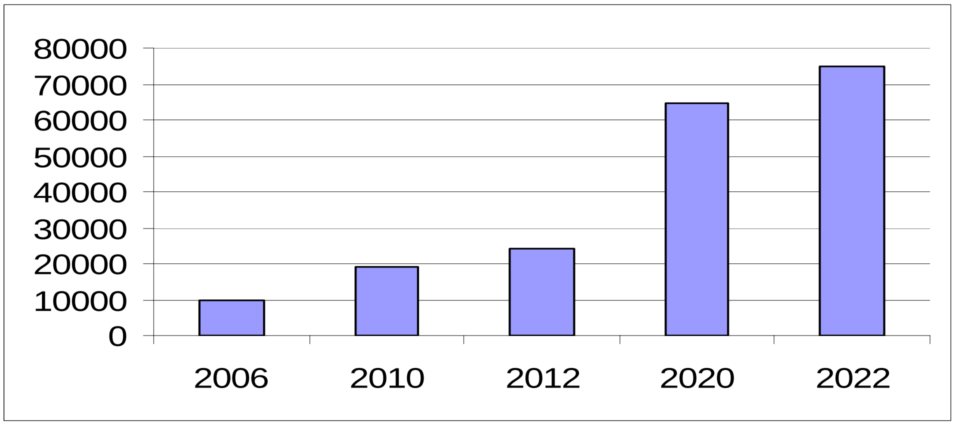

Figure 2. Relative changes in total indirect utility for years 2006-2022 in 100 000 NOK

Development of transport infrastructure reduces costs of transportation between the regions and hence increases total transport flow in the economy. Additional transport flow, which is due to the infrastructure extension, increases over time and is rather significant as measured in tons. Additional increase in transport flow leads to the external costs such as pollution, noise and congestion that are not taken into account in the model and hence are not included into the analysis. Additional external costs may significantly reduce welfare benefits and hence should be accounted for.

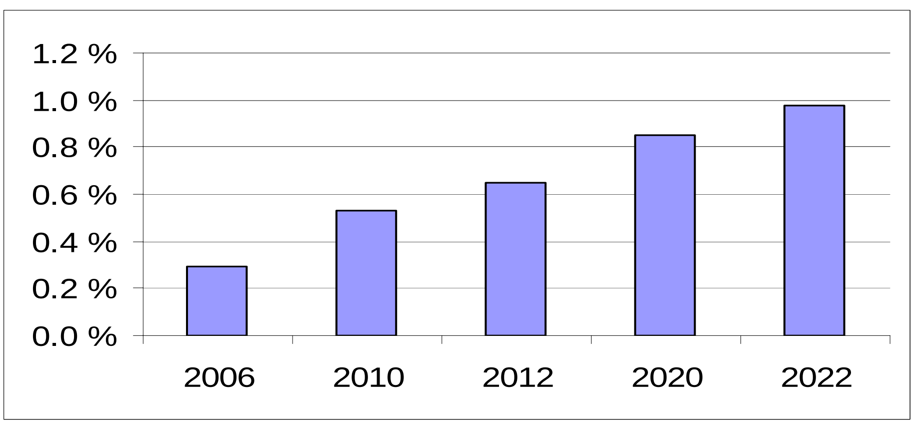

Figure 3. Relative changes in total transport flow for years 2006-2022 in percent

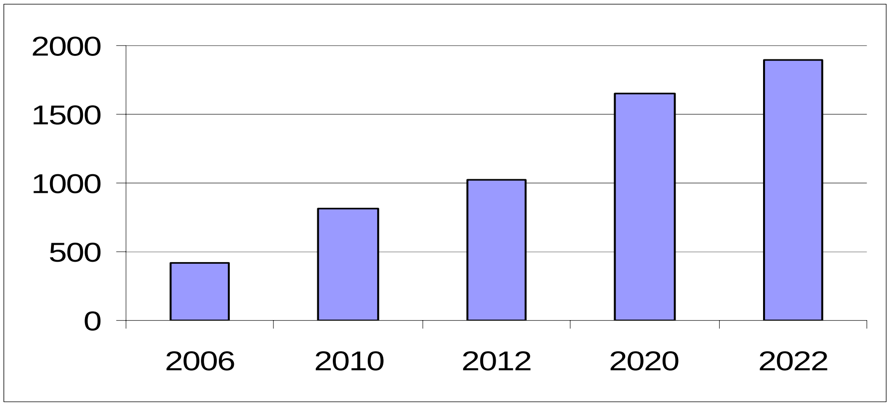

Figure 4. Relative changes in total transport flow for years 2006-2022 in 100 000 tons

3.3. Regional changes

PINGO represents Norwegian economy as consisting of 19 different geographical regions as illustrated at Figure 5.

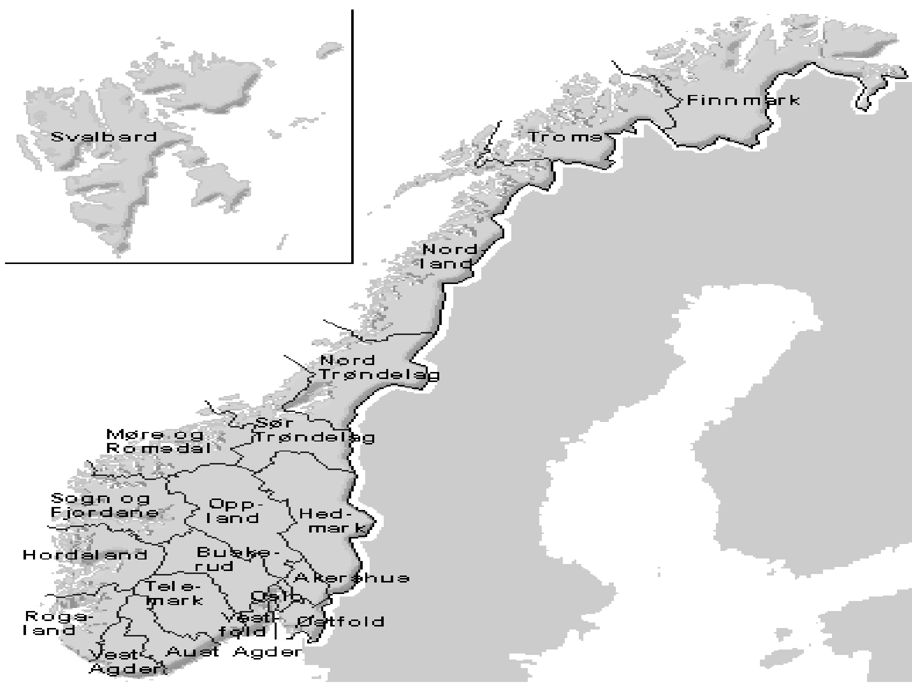

Figure 5. Regions of Norway: 01 Østfold, 02 Akershus, 03 Oslo, 04 Hedmark, 05 Oppland, 06 Buskerud, 07 Vestfold, 08 Telemark, 09 Aust-Agder, 10 Vest-Agder, 11 Rogaland,12 Hordaland, 14 Sogn and Fjordane, 15 Møre and Romsdal, 16 Sør-Trøndelag, 17 Nord-Trøndelag, 18 Nordland, 19 Troms, 20 Finnmark.

Implementation of different separate infrastructure projects or packages of projects influence differently economic performances of the regions. Some of them may receive competitive advantages over the others as the result of infrastructure improvements. SCGE models like PINGO allow for rather detailed analysis of regional changes and, hence, welfare benefit analysis of a particular infrastructure investment package may be performed for each region of Norway separately. Let us consider how the investment package proposed by the Ministry of Transport for 2006-2022 influences economic performances of the regions. Since the package consists of projects relatively uniformly spread all over the country one would not expect any striking differences in regional economic performances as the result of its implementation.

In order to derive relative changes in indirect utilities, consumption and transport flows arising due to infrastructure development i.e. reduction in transport costs, there are again considered the following two scenarios: one without infrastructure improvements and one with them. Both scenarios include annual economic growth rates as given by Tables 1-3. In order to simulate the economic growth path PINGO have been solved for each year of the period 1999-2022 and SAM matrix has been updated after each year in order to account for changes in consumption and transport patterns. Afterwards the growth rates of consumption, indirect utilities and transport flows that are due to infrastructure improvements have been derived using the respective values from two scenarios. The growth rates have been transformed into monetary units by multiplying them with monetary values for the scenario without infrastructure improvements.

As illustrated on Figures 6 and 8, although the investment package proposed by the Norwegian Ministry of Transport does not discriminate any geographical region there is a large difference between the welfare benefits of regions from infrastructure improvements, even when one compares benefits measured in percent. According to Figure 6 the highest welfare benefit (for Nordland) is twice as large as the smallest welfare benefit (for Nord-Trøndelag), which demonstrates significant differences in effects of infrastructure improvements on economic performances of the regions. From 2006 to 2022 the difference between highest and smallest welfare benefits measured in percent is reduced and in 2022 Aust-Agder benefits least and Telemark most (Figures 6 and 8). One may conclude that regional differences in welfare benefits of the regions are reduced with time, which is due to the process of adaptation to transport infrastructure changes. Differences in welfare benefits of the regions in monetary units are even more striking and are attributed to initial inequalities between the regions (Figures 7 and 9). Hence, from the point of view of different regions the same infrastructure project may be both profitable and unprofitable.

Figures 6-9: Relative changes in the indirect utilities of representative households for the years 2006 and 2022 measured in percent and in monetary units.

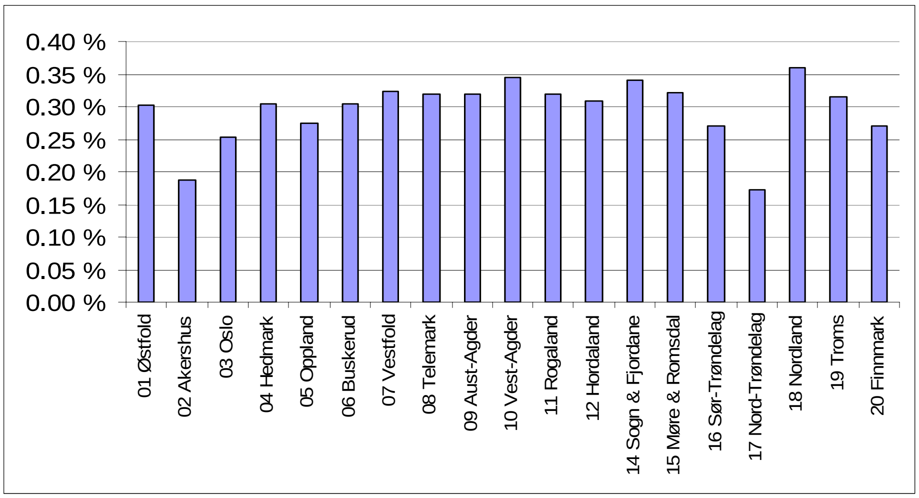

Figure 6. Relative changes in the indirect utilities of representative households in 2006 in percent

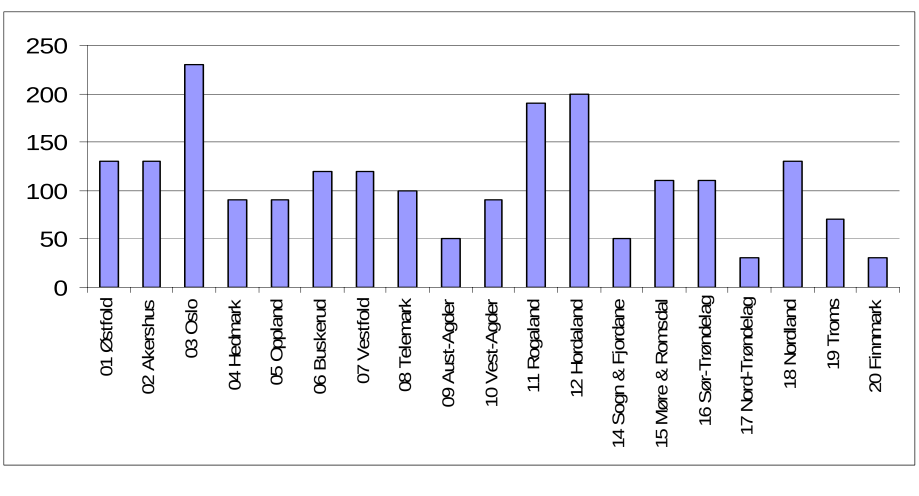

Figure 7 Relative changes in the indirect utilities of representative households in 2006 in 100 000 NOK

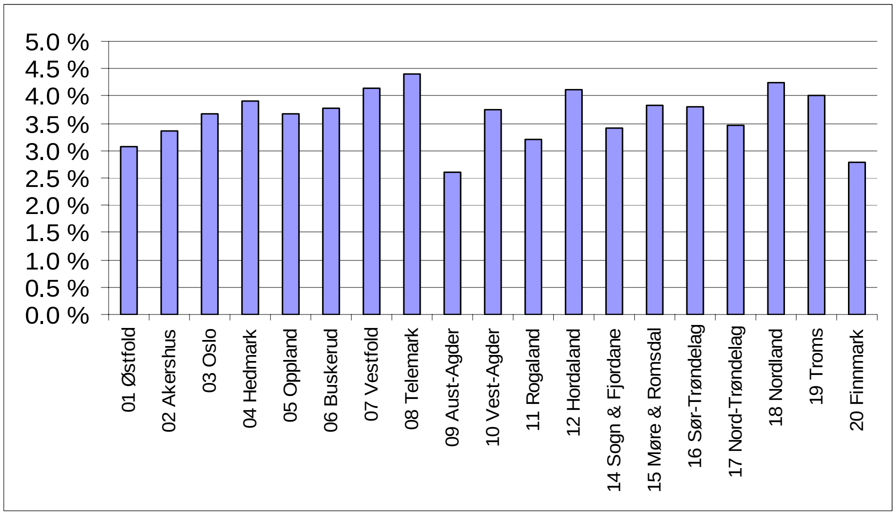

Figure 8. Relative changes in the indirect utilities of representative households in 2022 in percent

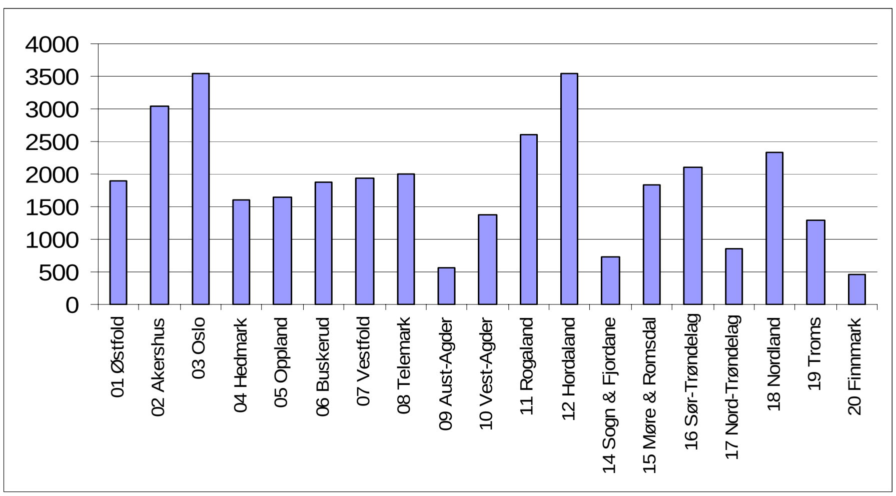

Figure 9. Relative changes in the indirect utilities of representative households in 2022 in 100 000 NOK

Welfare benefits of the regions are associated with changes in patterns of transport flows between them, induced by infrastructure improvements. Increased total transport flow to a region is the sign of increase in economic activities such as consumption and production inside it and hence means positive welfare changes. The differences between additional transport flows into the regions, generated by infrastructure improvements, are not that large as demonstrated on Figure 10 and do not directly correspond to the differences in welfare benefits of the regions. This is due to the fact that changes in total transport flows to the regions do not capture all changes in transportation patterns.

The differences between additional transport flows increase over time (Figure 12) and in 2022 it is the northern territories that have the largest additional transport flows, with the highest additional flow (into Nordland) being twice as large as the smallest additional flow (into Aust-Agder). The initial transport infrastructure and geographical position of northern territories make it difficult to access them and hence future development of infrastructure has the largest effect on their transport flows in the long run, relatively to the regions with good initial accessibility. Increased differences between additional transport flows of the regions demonstrate that adaptation process takes place and allows transport patterns to be changed in such a way, that differences in welfare benefits of the regions are reduced.

According to Figures 11 and 13, representing additional transport flows to the regions in tons, the largest additional flows are associated with the most populated and industrialized regions of the country: Akershus, Oslo, Rogaland and Hordaland. Large differences between the additional transport flows in tons are explained by initial differences between the regions as well as by initial transport infrastructure of the country.

Figures 10–13: Relative changes in total transport flows to the regions for the years 2006 and 2022 measured in percent and in tons.

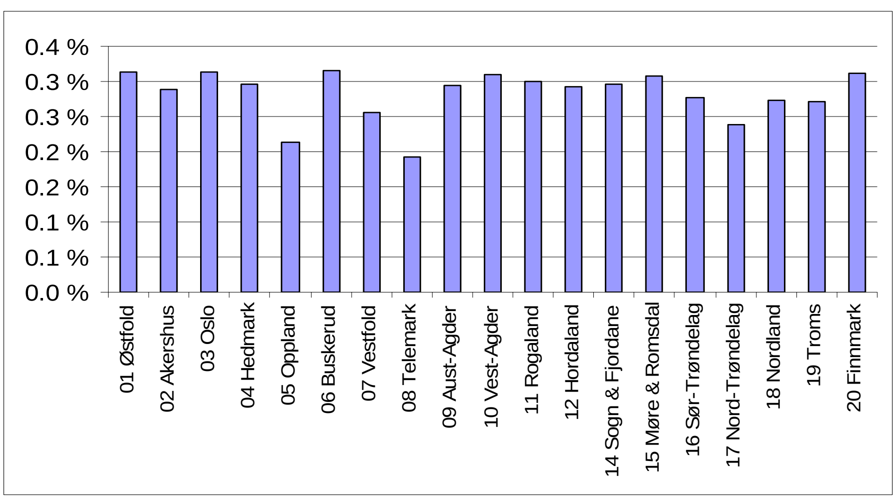

Figure 10. Relative changes in total transport flows to the regions in 2006 in percent

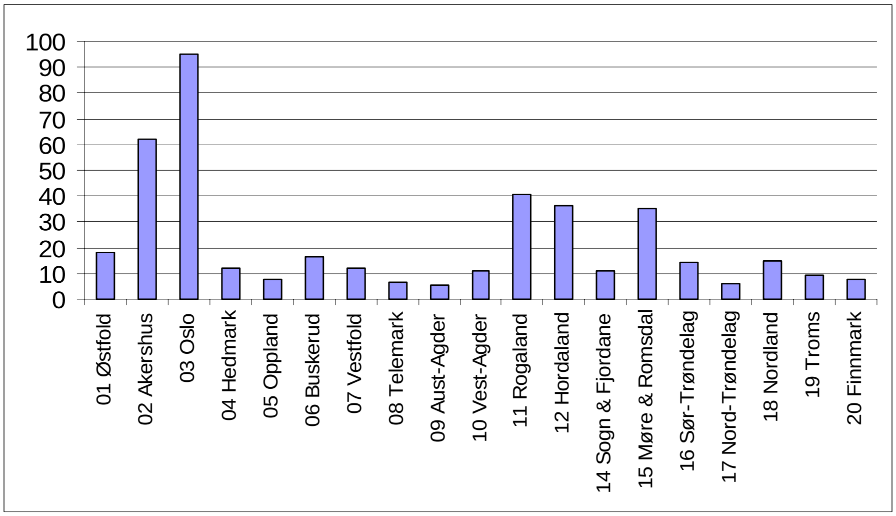

Figure 11. Relative changes in total transport flows to the regions in 2006 in 100 000 tons

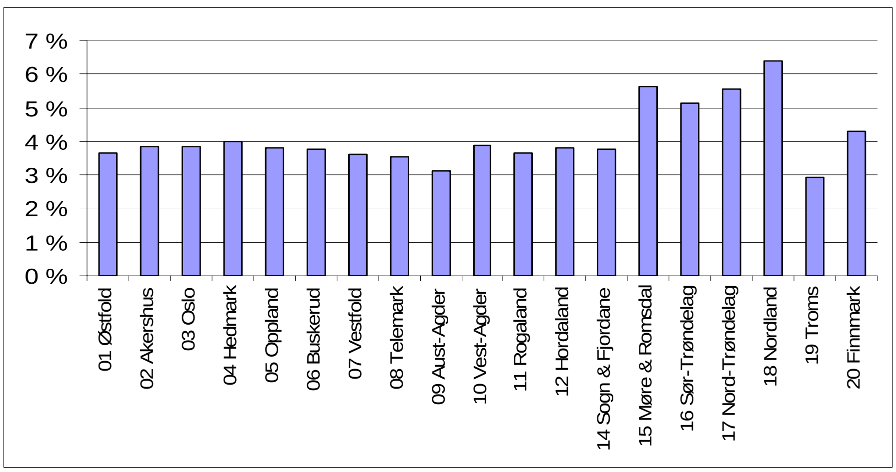

Figure 12. Relative changes in total transport flows to the regions in 2022 in percent

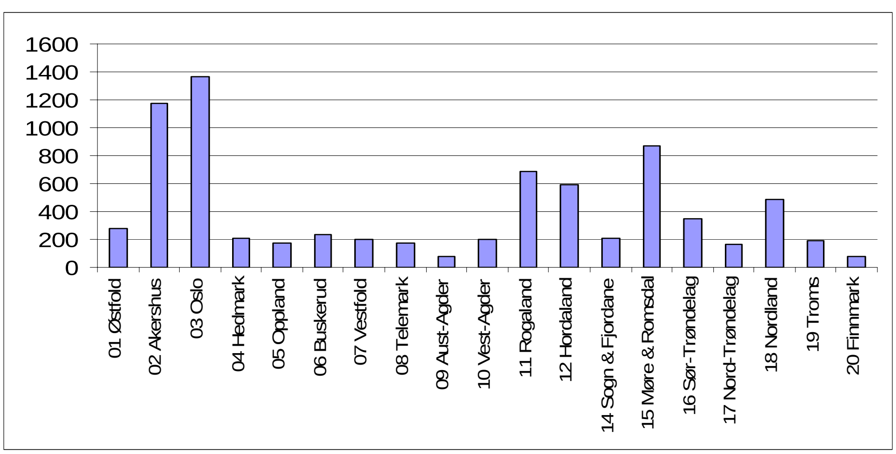

Figure 13. Relative changes in total transport flows to the regions in 2022 in 100 000 tons

4. Prediction of future transport flows

As was demonstrated in the previous section, in the presence of economic growth transport infrastructure development leads to rather large welfare benefits for the society, whereas the lack of it leads to inevitable welfare loss even in a developed country like Norway. Hence, transport infrastructure is regarded as a critical success factor for competitive performance and internalization of regional economies. One should be aware that missing links and even more missing networks mean a significant reduction in the potential productivity of a region or a nation.

Regional development is not only the result of proper combination of private production factors such as labor, capital and land, but also infrastructure in general and transport infrastructure in particular. A neglect of infrastructure leads to lower productivity of other production factors and vise versa. The desired balance between private capital and infrastructure is subject to a lot of theoretical and ideological debate. Hirschman (1958) has pointed out that a structural balance is not possible due to the lumpiness of transport infrastructure projects, which means that one has relatively long periods of excess supply or demand.

Governments have different options with respect to transport infrastructure decisions. First, they may invest in infrastructure as a response to serious bottlenecks taking place due to expansion of a private sector. This is a passive strategy: investments in infrastructure follow an expansion of production and, hence, an increase in freight transport flows. Another option is that governments use infrastructure to stimulate national economy and increased production. This is an active strategy: investments are made beforehand and there is no shortage of infrastructure in the future. This type of strategy has risky element in it, since forecasts of future possible bottlenecks may be imprecise.

Such SCGE model as PINGO gives governments the possibility to foresee future needs of an economy in transport infrastructure and to make transport investments beforehand in order to escape any serious bottlenecks and stimulate economic growth.

Demand for transportation services as well as future freight transport flows depend upon the future levels of all economic activities. The growth rates of production, export and import from Tables 1-3 are used as inputs into PINGO and allow for deriving annual growth rates of transport flows for each commodity group between all pairs of regions.

Given such growth rates one may predict transport flows between the regions for a particular period of time

Information about future transport flows allows governments to analyze possible bottlenecks between pairs of regions and consider solutions for the problem. In order to perform such an analysis on the level of particular transport links, results of the SCGE model in the form of growth rates should be used as inputs to the national real network model (NEMO), so that a transport flow on each particular link of the network is derived. Comparing predicted transport flows with present capacities of the links one identifies the need for improvement of a particular link or for construction of a new additional link.

Predictions with the model have been performed under the assumption of no changes in present transport infrastructure of the country. Growth rates of total transport flow for each pair of regions and each commodity group have been derived for periods 1999-2006, 1999-2012 and 1999-2022. Weighted average growth rates for each pair of regions have been calculated, where weights are equal to the proportions of commodity groups in the total flow between pairs of regions in the base year (1998). The resulting four maximum weighted average growth rates for each period under consideration are represented on Figures 14-16.

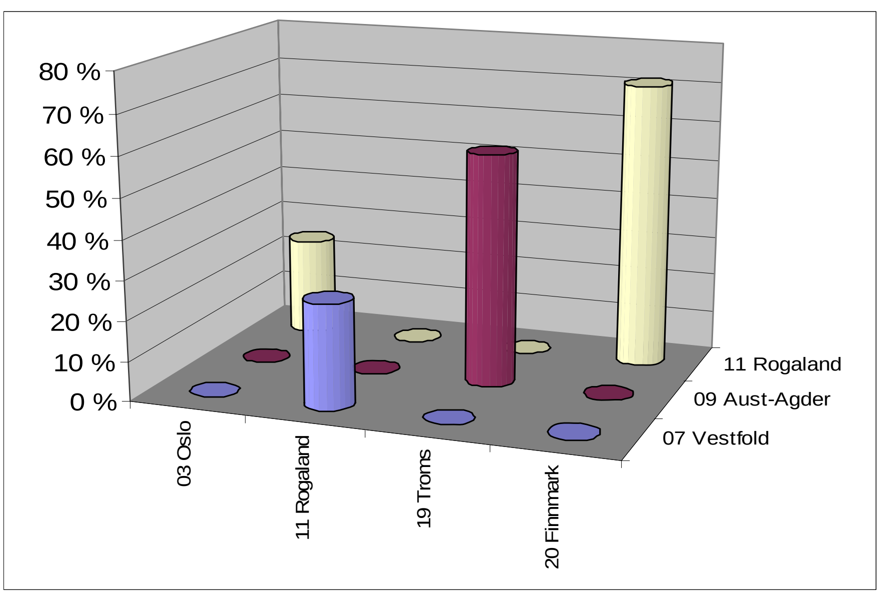

Figure 14. Maximum weighted average growth rates for the period 1999-2006

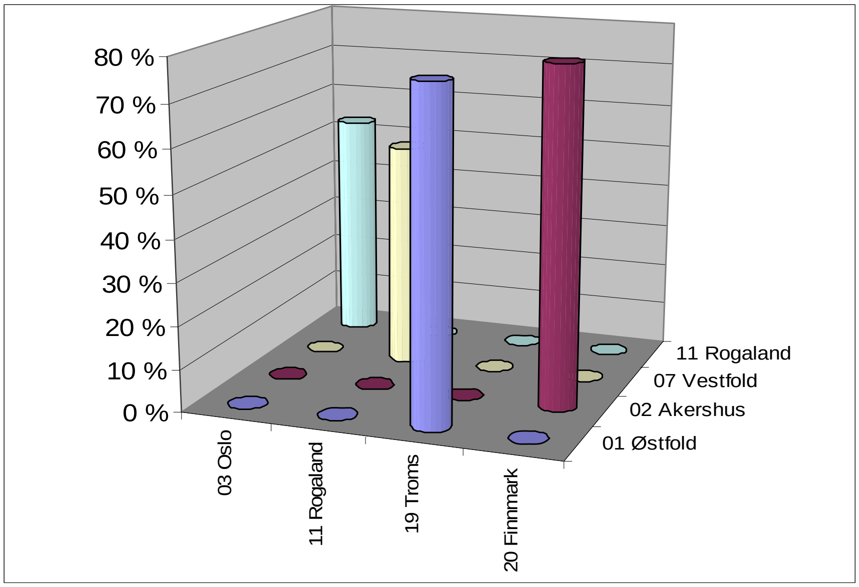

Figure 15. Maximum weighted average growth rates the period 1999-2012

Increase in transport flows between the particular regions presented on Figures 14-16 is very large and it is evident that the present capacity of transport infrastructure is not enough to meet future needs of the economy. The predicted bottlenecks involve Oslo geographical area, a number of northern regions (Troms, Finnmark) as well as the most industrialized regions of Norway (Rogaland, Hordaland). The future development of transport infrastructure should be focused on better communication between these three geographic areas. The package of transport projects proposed by the Norwegian Ministry of Transport focuses a lot upon Oslo area (Oslo, Akershus, Vestfold, Østfold) as well as upon South-Vest industrial area (Hordaland, Rogaland, Sogn & Fjordane), which is consistent with the elimination of predicted bottlenecks, but does not have enough projects for northern territories. There is a need for improved communication between industrial area and northern territories, which should be accounted for while constructing infrastructure projects.

In order to find out concrete transport links with the maximum flow increase on the real transport network one may use growth rates for transport flows from PINGO as an input to the national strategic network model (NEMO).

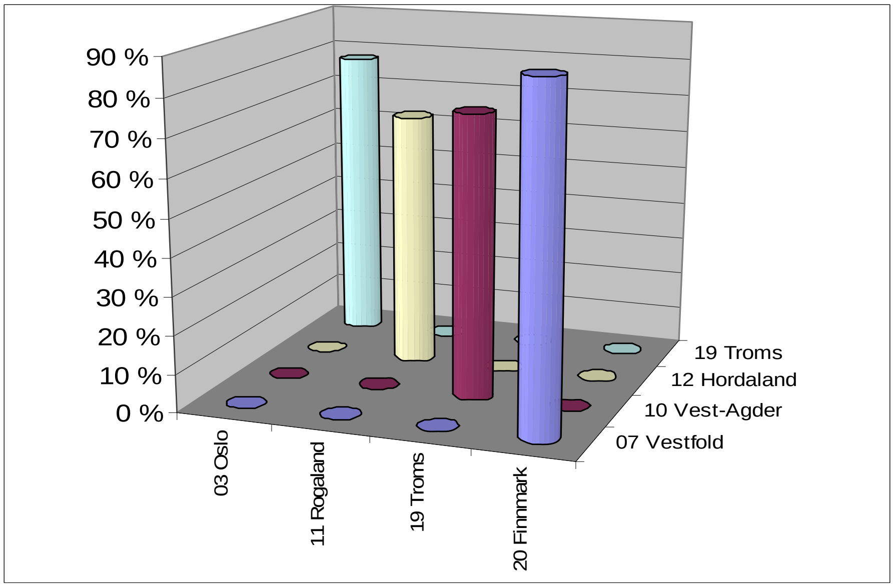

Figure 16. Maximum weighted average growth rates for the period 1999-2022

5. Concluding remarks

In a developed country like Norway, with elaborated transport infrastructure, introduction of new transport links alone does not lead to large welfare benefits or effects on economic performance, as it would be in a developing country. It is rather the lack of necessary infrastructure improvements under the condition of fast economic growth, which may cause troubles and result in significant losses of welfare.

The presence of economic growth in the analysis increases significantly the value of welfare benefits and allows one to conclude, based on the empirical analysis performed in the paper, that the lack of adequate infrastructure leads to inevitable welfare loss for an economy even in countries will elaborate transport infrastructure. Transport infrastructure should be accounted for as an important economic resource, the lack of which prevents normal economic development. Hence, governments' role is to foresee future needs of an economy in transport infrastructure and fulfill them in the best way. This means not only preventing possible future bottlenecks but also choosing investment packages with the highest welfare benefits. SCGE models like the one used in the paper may help governments a lot in fulfilling these tasks.

The SCGE model used in the paper proved to be a useful instrument in calculating welfare benefits of infrastructure investment packages. The model captures most micro-economic effects of transport infrastructure improvements, such as reduction in the production costs to individual businesses as the result of decreased transport costs. It also captures partly some regional effects, for example changes in trade patterns between the regions. However, the model does not capture a large part of other important regional effects. Such important issues as influence of changes in transport infrastructure upon locations of households and firms as well as upon structure of markets are not represented at all. Since the model is rather aggregated one, that is representing the whole country as consisting of a restricted number of regions, only significantly large infrastructure improvements and investment packages may be analyzed with it. Hence, there is a need for future development of the model in order for all the mentioned issues to be accounted for.

The effects of transport infrastructure improvements at the level of real network performance are treated rather rudimentary by the model. The SCGE model by itself does not incorporate real transport network equilibrium. Instead, the growth rates of transport flows between the regions are used as input to the national real freight network equilibrium model, which calculates respective changes in transport routes and transport flows on the links of network. Such one-sided relationship between the models does not allow for calculating simultaneous equilibrium for both SCGE model and network equilibrium model and hence performed analysis cannot be considered to be complete. In order to represent the effects of transport infrastructure improvements at the level of real network performance one should incorporate both real freight network equilibrium and real passenger network equilibrium into the model.

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Chapter 2

Bi-level programming in network design

Efficiency of a city transport network may be significantly improved by correct allocation of infrastructure investments. In most cases welfare benefits of such investments are interrelated and hence cannot be estimated separately. In order to allocate investments in the best way, one should consider all possible combinations of infrastructure projects and evaluate their benefits using the network equilibrium concept. In most contemporary applications network equilibria for car and public transport are formulated as two separate models. The main aim of present paper is to present a new formulation of simultaneous network equilibrium for car and for public transport in the form of single Mixed Complementarity Problem. This formulation makes it possible to implement network equilibrium without use of special transport packages as well as to incorporate it into the bi-level programming framework, with the help of which one may evaluate welfare benefits of large number of infrastructure project combinations during reasonable amounts of time. The paper also traces relationship between functional form of social welfare measure and ordering of infrastructure project combinations using Oslo/Akershus case-studio.

1. Introduction

Communication via transport network is an important part of everyday life in any city. Demand for traveling exists due to the spatial nature of economic activities. Demand and supply of labor are divided by space. Hence, there is a need in job trips of citizens. Demand and supply of goods and services are also divided by space, which gives rise to shopping trips. Commuting between residence-job and residence-shop pairs of locations performed by citizens is crucial for functioning of an economy of a city. Hence, efficient transport network is needed for it to develop normally.

Efficiency of a transport network may be significantly improved by the correct allocation of infrastructure investments. In most cases infrastructure investment projects for a city are interrelated and their benefits cannot be estimated independently. Hence, in order to allocate investments in the best way inside a city, one should consider all possible combinations of proposed infrastructure projects and choose the most optimal one. Transport infrastructure is a public good, provided by a transport ministry. Hence, the most natural criterion for choice of the best combination of investment projects is the maximization of social welfare. In order to be able to calculate the social welfare for any given combination of infrastructure projects, a transport ministry should be able to foresee the changes in travel behavior of citizens, which are the result of new investments.

Travel behavior of citizens is summarized in the form of network equilibrium model that describes behavior of both car users and public transport users. A transport system is in equilibrium, when each network user (citizen) chooses route with the smallest transport costs, given route choices of all other users. None of the network users finds it worthwhile to deviate from his equilibrium route, if the others do not deviate. Network equilibrium depends upon a network structure and hence is influenced by infrastructural improvements.

By solving network equilibrium model for each combination of infrastructure projects, a transport ministry is able to get the forecast of travel behavior of citizens and hence calculate the social welfare measure. In order for a transport ministry to be able to consider significant number of infrastructure projects and hence increase the probability that chosen combination is close to the ultimate optimum, solution time of the network equilibrium model should be as small as possible. The optimality of chosen combination of investment projects also depends upon the functional form of social welfare measure as well as upon the effective investment budget restriction.

The present paper has the following related aims. The first one is to formulate the simultaneous network equilibrium for both car and public transport in the form of Mixed Complementarity Problem and incorporate it into bi-level programming framework. The second aim is to investigate the role, which functional form of social welfare measure plays in optimal infrastructure investment choice using Oslo case-studio.

The model presented in the paper has a structure of bi-level programming or leader-follower game (Macrotte, 1986), where a transport ministry is the leader and citizens are the followers. The lower level of the bi-level programming represents changes in traveling behavior of citizens for a given allocation of investments. The upper level represents the choice of investments allocation by a transport ministry in order to maximize social welfare.

Travel behavior of citizens is usually represented in the form of network equilibrium model (Macrotte, 1986). In most contemporary applications network equilibria for car and public transport networks are formulated as two separate equilibrium models, so that their simultaneous equilibrium is found by using an iterative procedure (Cea and Fernandez, 1993; Ferris et al, 1998; Spiess and Florian, 1989).

The main contribution of the paper is that it presents a new formulation of simultaneous network equilibrium for car and public transport in the form of single Mixed Complementarity Problem (MCP), which allows one to skip iterative procedure and hence to save considerable amounts time. Moreover, this formulation gives one a possibility to integrate the network equilibrium into bi-level programming framework using such modeling systems as GAMS, Mathematica and Matlab. Hence, a transport ministry is able to consider all combinations of possible infrastructure investments and hence increase probability that the chosen variant is close to the ultimate optimum. The formulation of network equilibrium in the MCP form is also easily integrated with Spatial General Equilibrium models and land-use models, since they are formulated in the same functional form.

The paper is organized as follows. In Section 2 mathematical formulation of the model is given. In Section 3 the model is implemented for Oslo case-studio. Section 4 concludes the paper.

2. Mathematical formulation of the model

A model of the bi-level programming structure is usually called the Network Design Problem (NDP) , when the decisions of regulator (transport ministry) concern the structure of transport network (the best infrastructure investments allocation) . NDP is widely used in many applications of transport economics. The model developed in the paper is of usual NDP type and consists of the following two levels of problems: upper level problem representing the decision making of transport ministry and lower level problem representing the travel behavior of transport network users (citizens).

Choice of the best infrastructure investments allocation by a transport ministry is restricted by a certain number of available infrastructure projects as well as all possible combinations of them. Infrastructural investment projects on a city transport network include building of new car roads and modernizing old ones, as well as designing new public transport lines or developing old ones and changing frequency on them. Hence, decisions of a transport ministry influence not only car users but also those using public transport.

Transport investment projects are, in general, interdependent, which means that the welfare gains of a given project depend upon a combination of other projects implemented at the same time or before it. Hence, in order to find the best combination of projects, a transport ministry should consider all possible combinations of them and choose the best one according to the social welfare maximization criteria, taking into account budget restriction on the amount of infrastructure investments. A transport ministry may use different functional forms of social welfare measure, depending upon its preferences and available level of informational details. In general, a welfare measure should reflect the effects, that infrastructure investments have upon all transport system actors such as travelers, public transport operator and government.

In order for a transport ministry to be able to estimate the social welfare measure for each possible combination of infrastructure investment projects, it should be able to foresee the changes in behavior of network users as a result of changes in the transport network. Since, investment projects under consideration may in general concern transportation by car as well as transportation by public transport, the following two transport networks are considered in the model: car network and public transport network. Consequently, all citizens are divided into those traveling by car and using car network as well as those traveling by public transport and using public transport network. Both transport networks consist of nodes, representing particular residential locations of citizens and locations of economic activities inside a city and links connecting them. Links of the car network represent car roads, while links of the public transport network represent parts of public transport lines, so that each public line consists of a particular sequence of links. It is supposed that both transport networks have the same nodes but links between them may differ.

There are a particular number of citizens at each residential location of transport network, who decide where and how there are going to travel, taking into account the structures of car transport and public transport networks. Travel behavior of the citizens is fully described by their decisions about destination and mode (car or public transport) of their trips as well as by their decisions about which transport network links to use while traveling (route choice). The citizens' choice of destination and mode of their trips is fully described by their elastic travel demand functions and depends upon the generalized travel costs by car and by public transport between each pair of nodes.

The generalized costs of traveling by car and by public transport between each pair of nodes consist of time costs in monetary value plus some monetary costs such as ticket price or spending on petrol and depend upon the routes on transport networks chosen by citizens. In most applications equilibria for car transport and public transport networks are formulated separately. The models may be formulated in the form of non-linear maximization problems or in the form of equivalent variation problems (Cea and Fernandez, 1993; Ferris et al, 1998; Spiess and Florian, 1989).

The model developed in the paper uses different formulation of travelers' route choice problem. The problem is formulated as the simultaneous equilibrium for both car network users and public transport network users. Hence, the route choices of both classes of users are performed at the same moment of time and independently of each other. In this case network equilibrium is formulated in the form of Kuhn-Tucker conditions for the two nonlinear maximization problems, one for car network equilibrium and one for public transport network equilibrium. Such reformulation of the problems gives possibility to solve them simultaneously and to find the optimal route choices on both transport networks as a solution of the single equilibrium problem.

2.1. Formulation of the simultaneous equilibrium on car and public transport networks

In order for a transport ministry to choose the best combination of infrastructure investment projects it should be able to calculate the given social welfare measure for each of them. The social welfare measure of new investments depends upon changes in the behavior of network users, consisting of changes in their travel demands as well as changes in their optimal route choices, being calculated using the network equilibrium model.

Route choices of citizens are performed on the following two different transport networks: car network and public transport network. Both networks consist of the same nodes, representing residential locations and locations of economic activities inside a city, and different links between them. The collection of links between nodes of a given transport network is called the structure of network and it may be described using binary parameters. In general, there may be more then one link connecting a pair of nodes. In case of the car network, they are interpreted as alternative roads and are enumerated with the whole numbers. In case of the public transport network, they are interpreted as parts of different public lines and are enumerated according to the line they belong to. All links of the transport network are directed, which means that for a pair of nodes *i* and *j* there is a separate link leading from node *i* to node *j* and a separate link leading from node *i* to node *j*.

Denote by δ_{ijn} a binary parameter representing the structure of car network, which equals unity if there exists a link number *n* leading from node *i* to node *j* and zero otherwise. In the same manner, denote by γ_{ij}^{r} a binary parameter representing the structure of public transport network, which equals unity if there exists a link of public line *r* leading from node *i* to node *j* and zero otherwise.

Each link of the transport network is associated with a generalized cost function representing both time costs in monetary value and monetary costs of traveling on the link. The generalized costs of traveling between each pair of nodes depend upon the route choices of citizens and are the sum of generalized link costs along the chosen route. The generalized travel costs for car c_{ij}^{car} and for public transport c_{ij}^{pub} define travel demands of the citizens according to the elastic travel demand functions $D_{ij}^{car}(c_{ij}^{car}, c_{ij}^{pub})$ and $D_{ij}^{pub}(c_{ij}^{pub}, c_{ij}^{car})$.

Generalized cost functions of car network links are denoted by $c_{ijn}(f_{ijn})$ and are increasing functions of total car flow on the link, f_{ijn}. These functions include time travel costs measured in monetary units, spending on petrol and other possible monetary costs, such as road charges for example. Generalized link cost functions also represent the phenomenon of congestion on city roads, which leads to increase in travel times on the links and hence increase in generalized link costs. The generalized travel costs for car c_{ij}^{car} are the sum of generalized link costs along the links of optimal route from node i to node j.

Generalized travel costs for public transport c_{ij}^{pub} consist not only of link costs t_{ijr} associated with each link of the public transport network, but also of waiting costs $w_{ijr'r}(f_{ijr}^{p})$ while changing line r' for line r at node i, that are increasing functions of passenger flow on the link f_{ijr}^{p} and depend upon frequencies of the lines g_r. One should also account for ticket prices t_{ij}^{pub} that are defined for each pair of nodes and fixed outside the model. The total generalized travel costs for public transport consist of c_{ij}^{pub} that are calculated inside the model and t_{ij}^{pub} that are fixed outside the model.

The optimal route choices of network users may be represented in the form of nonlinear maximization problem such that the sum of network users' benefits minus the sum of network users' generalized travel costs is maximized under the restriction that travel demands are fully satisfied. For the car network this problem is written in the following form (Ferris et al, 1998):

$$\max_{x_{ijn}^{k},d_{ik}^{car}} \sum_{k}\sum_{i} \int_{0}^{d_{ik}^{car}} D_{ik}^{car^{-1}}(x)dx - \sum_{i}\sum_{j}\sum_{n} \int_{0}^{f_{ijn}} c_{ijn}(x)dx \quad \text{subject to}$$

$$\sum_{j}\sum_{n} x_{ijn}^{k}\delta_{ijn} - \sum_{j}\sum_{n} x_{jin}^{k}\delta_{jin} = d_{ik}^{car}$$

$$f_{ijn} = \sum_{k} x_{ijn}^{k}$$

where

x_{ijn}^{k} is a car flow on a link number n from node i to node j with destination at node k.

d_{ik}^{car} is a demand for traveling by car from node i to node k. $D_{ik}^{car}(\cdot)$ is a demand for traveling by car from node i to node k, as a function of generalized costs of traveling by car from node i to node k, where generalized costs of traveling by public transport from node i to node k are supposed to be fixed outside the model. $D_{ik}^{car^{-1}}(\cdot)$ is an inverse demand function, which may be interpreted as generalized costs of traveling by car from node i to node k , as a function of a demand for traveling by car from node i to node k , where a demand for traveling by public transport from node i to node k is supposed to be fixed outside the model.

Similar nonlinear maximization problem for the public transport network may be formulated as follows:

$$\max_{y_{ijr'r}^k, w_{ijr'r}, d_{ik}^{pub}} \sum_k \sum_i \int_0^{d_{ik}^{pub}} D_{ik}^{pub^{-1}}(x)dx - \sum_k \sum_i \sum_j \sum_r y_{ijr}^k t_{ijr} - \sum_i \sum_j \sum_{r'} \sum_r \int_0^{f_{ijr}^p} w_{ijr'r}(x)dx \quad \text{subject to}$$

$$\sum_j \sum_{r'} \sum_r y_{ijr'r}^k \lambda_{ijr'r} - \sum_j \sum_{r'} \sum_r y_{jir'r}^k \lambda_{jir'r} = d_{ik}^{pub}$$

$$f_{ijr}^p = \sum_k \sum_{r'} y_{ijr'r}^k$$

where

$y_{ijr'r}^k$ is a flow of passengers on a link from node *i* to node *j*, which belongs to the public line *r*, with destination at node *k*, who change line r' for line *r* at node *i*. $\lambda_{ijr'r} \in \{0,1\}$ are derived in the following way $\lambda_{ijr'r} = \max\{\max_k\{\gamma_{ki}^{r'}\}, \gamma_{ij}^r\}$. It equals unity, when there is a possibility to change line r' for line *r* at node *i* and continue traveling on link from node *i* to node j. d_{ik}^{pub} is the demand for traveling by public transport from node i to node k. $D_{ik}^{pub}(\cdot)$ is the demand for traveling by public transport from node i to node k , as a function of generalized costs of traveling by public transport from node i to node k , where generalized costs of traveling by car from node i to node k are supposed to be fixed. $D_{ik}^{pub^{-1}}(\cdot)$ is an inverse demand function, which may be interpreted as generalized costs of traveling by public transport from node i to node k , as a function of the demand for traveling by public transport from node i to node k , where the demand for traveling by car from node i to node k is supposed to be fixed.

The model proposed in the paper allows one to formulate optimal route choice problems for the car network and for the public transport network as the single optimal route choice problem and hence solve them simultaneously. This is done by reformulating the nonlinear maximization problems in the form of their Kuhn-Tucker conditions in the following way:

$$\sum_j \sum_n x_{ijn}^k \delta_{ijn} - \sum_j \sum_n x_{jin}^k \delta_{ijn} = D_{ik}^{car}(c_{ik}^{car}, c_{ik}^{pub} + t_{ik}^{pub}) \quad (3)$$

$$c_{ijn}(f_{ijn}) + c_{jk}^{car} - c_{ik}^{car} \geq 0 \perp x_{ijn}^k \geq 0 \quad (4)$$

$$f_{ijn} = \sum_k x_{ijn}^k \quad (5)$$

$$\sum_j \sum_{r'} \sum_r y_{ijr'r}^k \lambda_{ijr'r} - \sum_j \sum_{r'} \sum_r y_{jir'r}^k \lambda_{ijr'r} = D_{ik}^{pub}(c_{ik}^{pub} + t_{ik}^{pub}, c_{ik}^{car}) \quad (6)$$

$$t_{ijr} + w_{ijr'r}(f_{ijr}) + c_{jk}^{pub} - c_{ik}^{pub} \geq 0 \perp y_{ijr'r}^k \geq 0 \quad (7)$$

$$f_{ijr}^p = \sum_k \sum_{r'} y_{ijr'r}^k \quad (8)$$

The mathematical formulation of network equilibrium (3)-(8) belongs to the wide class of mathematical problems called Mixed Complementary Problems (MCP), which has the following general mathematical formulation: $F(X) \geq 0 \perp X \geq 0$, where X is the vector of variables, $F(\cdot)$ is the operator and $\perp$ means orthogonal, that is if $X = 0$ then $F(X) > 0$ and alternatively if $X > 0$ then $F(X) = 0$.

In the formulation of simultaneous network equilibrium (3)-(8) the following variables are unknown: $x_{ijn}^k, y_{ijr'r}^k, c_{ij}^{car}, c_{ij}^{pub}$.

2.2. Formulation of the transport ministry maximization problem

A transport ministry decides upon the best combination of transport infrastructure projects on both car network and public transport network according to the maximum social welfare measure criteria. Possible investment projects consist of constructing new car roads or modernizing old ones as well as building new public transport lines, expanding old ones or increasing frequencies on them. Investment budget of a transport ministry is supposed to be fixed at the level of *B*, so that in order to find the best combination of infrastructure investment projects a transport ministry maximizes the social welfare function under the investment budget restriction.

In order to represent the transport ministry problem in the form of discrete optimization problem one should introduce some additional binary variables associated with investment projects. Let π_{ijn} be a binary variable associated with a construction of new car roads, which equals unity if an investment project of constructing a link number *n* from node *i* to node *j* on the car network is implemented and zero otherwise. Each such investment project has investment costs denoted by N_{ijn}. Let π_{ijn}^{mod} be a binary variable associated with a modernizing of old car roads, which equals unity if an investment project of modernizing a link number *n* from node *i* to node *j* on the car network is implemented and zero otherwise. Each such investment project has investment costs denoted by N_{ijn}^{mod}.

Let β^{r} be a binary variable associated with a construction of new public line, which equals unity if a public transport line *r* is established on the public transport network and zero otherwise. Each such investment project has investment costs denoted by M_{r}^{con}. Let η_{ij}^{r} be a binary variable associated with a construction of new link from node *i* to node *j*, which belongs to an existing public line *r*, which equals unity if such a link constructed and zero otherwise. Each such investment project has investment costs denoted by M_{ijr}.

Another possible investment project is an increase in frequency of an existing public transport line. Let us suppose that for each line we have a fixed number of different variants of frequency increase. Each variant is associated with certain investment costs. Let φ_{s}^{r} be a binary variable associated with variant number *s* of frequency increase for public line *r*, which equals unity if the variant is implemented and zero otherwise. Such investment project has investment costs denoted by M_{sr}^{freq}.

Given the introduced notation the transport ministry maximization problem is represented in the following way:

$$\max_{\pi_{ijn},\pi_{ijn}^{\mathrm{mod}},\beta^{r},\eta_{ij}^{r},\varphi_{s}^{r}} W(\pi_{ijn},\pi_{ijn}^{\mathrm{mod}},\beta^{r},\eta_{ij}^{r},\varphi_{s}^{r}) \tag{9}$$

subject to the budget restriction

$$\sum_{i,j,n}\pi_{ijn}N_{ijn}+\sum_{i,j,n}\pi_{ijn}^{\mathrm{mod}}N_{ijn}^{\mathrm{mod}}+\sum_{r}\beta^{r}M_{r}^{con}+\sum_{i,j,r}\eta_{ij}^{r}M_{ijr}+\sum_{r.s}\varphi_{s}^{r}M_{sr}^{freq}\leq B \tag{10}$$

The mathematical formulation of transport ministry maximization problem (9)-(10) should not be taken literally since social welfare function $W(\cdot)$ used in its formulation is not the usual function, but derived from solution to the network equilibrium formulation

(3)-(8) for each combination of infrastructure investment projects. This means that it is not possible to solve the transport ministry maximization problem directly using the formulation (9)-(10) according to the algorithms of discrete programming. Instead a transport ministry calculates the social welfare measure for each combination of infrastructure investment projects using solution of the network equilibrium in the formulation (3)-(8) and afterwards chooses combination with the highest social welfare measure.

2.3. Social welfare measure

The mathematical formulation of social welfare measure used by a transport ministry depends upon its preferences as well as upon the level of available information. It is supposed that a transport ministry is an egalitarian planner. Hence, it does not discriminate between different types of travelers as well as between different transport system actors in its social welfare function and treats everybody equally. In this case the functional form of social welfare depends only upon the level of informational details available to a transport ministry.

In order to formulate the social welfare function let us distinguish the following transport system actors: citizens traveling between the nodes of transport network either in the rush hour or during other periods of the day, public transport operator responsible for transportation on all the public lines and a government. Individual performance of each of these actors depends upon structure and characteristics of the transport network and hence is influenced by infrastructure investments. Benefits from infrastructure improvements received by different actors should be included into the social welfare function and equally accounted for by a transport ministry.

Infrastructure investments may have both positive and negative effects upon utility levels of transport network users (citizens). Related benefits are represented by the sum of consumer surpluses of citizens traveling in the rush hour CS^{rush} as well as during other periods of the day CS^{other}, where the total consumer surplus $CS = CS^{rush} + CS^{other}$. Negative effects of investments are due to negative environmental externalities and may be represented as the change in environmental damage costs *EC*, which is the result of infrastructure changes.

External costs of car traffic include environmental costs as well as noise and other possible costs. The costs, in general, depend upon the amount of traffic on the links as well as upon their geographical location inside the city. Let ec_{ijn} denote the external costs associated with an additional unit of traffic on a link number "*n*" between nodes *i* and *j*. The total external costs *EC* is calculated as follows:

$$EC = \sum_i \sum_j \sum_n \delta_{ijn} ec_{ijn} f_{ijn}$$

Public transport operator has control over all transport lines and charges travelers for using them. Each public transport line *r* is associated with operation costs O^r, which correspond to current structure of the line and current frequency on it. Changes in structure or frequency of the line are associated not only with a certain investment costs but also with additional operation costs for the public transport operator. Let us denote by OM^r additional operation costs associated with establishing/modernizing public transport line *r* and by OH_s^r additional operation costs associated with implementing a variant *s* of frequency on a public transport line *r*. Then the total additional operation costs associated with a combination of infrastructure projects are calculated as $\sum_r \beta^r OM^r + \sum_s \sum_r \varphi_s^r OH_s^r$.

Public transport charges are defined for each pair of origin-destination nodes and do not depend upon the set of public lines used by a traveler. Let us denote by t_{ij}^{pub} the public transport charge for traveling between origin-destination pair *(i,j)*, than the total revenue of public transport operator is calculated as $\sum_i \sum_j D_{ij}^{pub}(c_{ij}^{pub} + t_{ij}^{pub}, c_{ij}^{car}) \cdot t_{ij}^{pub}$.

For each combination of investment projects one may calculate the operative surplus of public transport operator as the difference between its revenue and operative costs:

$$OS = \sum_i \sum_j D_{ij}^{pub} t_{ij}^{pub} - \sum_r O^r - \sum_r \beta^r OM^r - \sum_s \sum_r \varphi_s^r OH_s^r$$

The operative surplus *OS* may be both positive and negative. The government has two options with respect to financing the public transport operator. One of them is to cover the whole negative surplus of the operator by using governmental revenue and expropriate the whole positive surplus in favor of the government. Another one is to cover/expropriate some fixed share $0 < \Phi < 1$ of operative surplus. In this case public transport charges should be high enough to cover the operative costs and ensure the public transport operator non-negative operative surplus.

The revenue from car road pricing received by the government is derived as the sum of total link flows times the car charge on a link calculated over the set of charged car network links. Let variable $\tau_{ijn} \in \{0,1\}$ represent the structure of charged links, that is τ_{ijn} equals unity if a link number "*n*" from node *i* to node *j* is under road pricing and zero otherwise. Each link under road pricing is associated with a specific charge p_{ijn} so that the total revenue from road pricing *RP* is calculated as follows:

$$RP = \sum_i \sum_j \sum_n \tau_{ijn} p_{ijn} f_{ijn}$$

The annuitant of total investment costs allows one to account for the magnitude of investments in the social benefit function. It is supposed that the lifetime of all infrastructure projects is thirty years and r^{disc} denotes discount rate used in calculations. The annuitant of total investment costs corresponding to a particular combination of infrastructure projects *A* is calculated as:

$$A = (\sum_i \sum_j \sum_n \pi_{ijn} N_{ijn} + \sum_r \beta^r M^r + \sum_s \sum_r \varphi_s^r H_s^r) \cdot \frac{r^{disc}}{1-(1+r^{disc})^{-30}}$$

In case when a transport ministry has high level of informational details the social welfare measure may include consumer surplus, change in operative surplus of public transport operator, change in governmental surplus times shadow price of public funds, change in external costs, which are due to implementation of infrastructure projects and annuitant of total investment costs. In order to calculate all its elements for a particular combination of investment projects simultaneous equilibria on car transport and public transport networks is found first for the current situation, when no investment projects is performed, and afterwards for the situation when a particular combination of investment projects is performed using the equilibrium formulation (3) – (8).

Given that the elements of social welfare measure, calculated for the current situation are denoted by subscript 0 and for the situation when a particular combination of infrastructure projects is performed are denoted by subscript 1, the social welfare measure *W* is calculated as follows:

$$W = CS + (1-\Phi)(OS^1 - OS^0) + p^{sh}\Phi(OS^1 - OS^0) + p^{sh}(RP^1 - RP^0) - (EC^1 - EC^0) - A \quad (11)$$

where p^{sh} denotes the shadow price of governmental funds.

The above formulation of social welfare measure is available only to a transport ministry possessing sufficient amount of information. In case when the level of information is low, the social welfare function should be simplified so that it includes just some elements of the formulated social welfare measure (11). Such simplification may, in general, influence the choice of the best combination of investment projects, which is tested in the next section of the paper using Oslo case-studio.

3. Implementation of the model for Oslo case-studio

Case-studio used for the analysis in this section covers the transport system of Oslo/Akershus region of Norway. It is a rather large part of Norway in terms of its population, which is about 700 000 citizens. Both road system and public transport system are well developed. There are four types of public transport in this region: metro, bus, tram, train and boat, with bus system being the most developed one. Road system is rather elaborated, but congestion is typical phenomenon in the rush hour. Car users pay a certain fee in order to enter the city. The level of information concerning transport system in the region is rather high, so that the social welfare measure in the sense of formulation (11) may be calculated.

Transport network of the region used for the analysis is simplified by including just major roads. Such simplification is acceptable since the analysis concentrates on the rush hour traffic, which uses mostly major roads. The nodes of transport network represent origins and destinations of traffic/passenger flows, which are called travel zones, as well as crossings of the roads and stops of the public lines. The travel zones used in the model correspond to official division of Oslo into city parts and of Akershus into communalities.

Demands for traveling by car and by public transport between the travel zones are derived from transport and location RETRO model for Oslo/Akershus (Vold, 2000). Demands for traveling between each pair of travel zones are fixed, but shares of people using car and public transport for moving between them are derived according to the elastic demand functions and depend upon the generalized travel costs.

A number of infrastructure project combinations are analyzed in this section, for each of them the network equilibrium model is solved and different types of welfare measures and transport system performance indicators are calculated according to the derived equilibrium volumes on the links.

3.1. Description of transport network

The Oslo/Akershus region is divided into 36 travel zones that correspond to the official division of Oslo into city parts and of Akershus into communalities as represented at Figure 2 in Appendix. Each travel zone shelters several network nodes that may be either origin/destination nodes and/or crossings of the roads and stops of the public lines. There are in total 53 network nodes in the model.

Transport network of Oslo/Akershus region consists of car network and public transport network, with the last one being constructed of (1) bus, (2) train, (3) metro, (4) tram, and (5) boat public lines, which are enumerated accordingly. Car and public transport networks are constructed using the same nodes and travel zones.

Car network used for the analysis includes just major roads of the region, which are divided into the four road classes: free-field highway, two-field highway, two-field city road and one-field city road. The generalized link costs depend upon the type of road this link belongs to. Car network of the region is represented at Figure 3 in Appendix and is a simplified version of the real one. Car users are charged a certain road tolls while entering the city.

Public transport network consists of five different public lines: bus, train, metro, tram and boat. The lines have different structure and frequencies. Frequencies for bus, metro and tram lines are four vehicles per hour, while for train and boat lines are two vehicles per hour. Bus public line has the most developed network structure, which is represented at Figure 4 in Appendix.

The following types of infrastructure improvements are defined on the transport network: construction of new roads, improvement of old roads, construction of new public lines links and increase in frequencies of public lines. Only two types of improvements have been used for the analysis performed in the paper: double increase in capacities of old roads between nodes 53 and 52, 52 and 51, 48 and 49, 33 and 32, 51 and 49, 51 and 50 as well as increase in frequencies of the public lines (2) train up to 4 vehicles per hour, (3) metro up to 5 vehicles per hour, (5) boat up to 4 vehicles per hour. Since investment projects used in the paper are hypothetical ones, there exists no information about their investment costs as well as changes in operational costs they induce. Hence, welfare functions chosen for the analysis do not take investment costs and changes in operational costs into account.

3.2. Description of travel demands

Travel zones used in the model correspond to the official division of Oslo into city parts and of Akershus into communalities. There are in total 35 travel zones and base case travel demands and travel costs are derived from RETRO model. Given base case values of rush hour travel demands and travel costs, one calculates the total budgets for traveling between each pair of zones. The total budgets are divided between car and public transportation during the rush hour according to the elastic demand functions of the CES functional form (Minken and Samstad, 2000):

$$D_{ij}^{car}(c_{ij}^{car}, c_{ij}^{pub} + t_{ij}^{pub}) = B_{ij} \frac{\left(\dfrac{\beta_{ij}^{car}}{c_{ij}^{car}}\right)^{1/(1-\mu)}}{\left(\dfrac{\beta_{ij}^{car}}{c_{ij}^{car}}\right)^{1/(1-\mu)} + \left(\dfrac{\beta_{ij}^{pub}}{c_{ij}^{pub} + t_{ij}^{pub}}\right)^{1/(1-\mu)}} \tag{11}$$

$$D_{ij}^{pub}(c_{ij}^{pub} + t_{ij}^{pub}, c_{ij}^{car}) = B_{ij} \frac{\left(\dfrac{\beta_{ij}^{pub}}{c_{ij}^{pub} + t_{ij}^{pub}}\right)^{1/(1-\mu)}}{\left(\dfrac{\beta_{ij}^{car}}{c_{ij}^{car}}\right)^{1/(1-\mu)} + \left(\dfrac{\beta_{ij}^{pub}}{c_{ij}^{pub} + t_{ij}^{pub}}\right)^{1/(1-\mu)}} \tag{12}$$

The total travel budgets B_{ij} and coefficients $\beta_{ij}^{car}, \beta_{ij}^{pub}$ of demand functions are derived from base case travel demands $d_{ij}^{car}, d_{ij}^{pub}$ and travel costs $s_{ij}^{car}, s_{ij}^{pub}$ in the following way:

$$B_{ij} = d_{ij}^{car} s_{ij}^{car} + d_{ij}^{pub}(s_{ij}^{pub} + t_{ij}^{pub})$$

$$\beta_{ij}^{car} = \frac{d_{ij}^{car}}{d_{ij}^{car} + d_{ij}^{pub}}$$

$$\beta_{ij}^{pub} = \frac{d_{ij}^{pub}}{d_{ij}^{car} + d_{ij}^{pub}}$$

The elasticity parameter μ is chosen in such a way that the modeling system reproduces the base case values of travel demands $d_{ij}^{car}, d_{ij}^{pub}$ in the situation when none of investment projects is implemented, that is in the base case situation. In the case of Oslo/Akershus model it equals –4, which corresponds to elasticity $\sigma = \frac{1}{1-\mu} = 0.2$.

Consumer surplus of network users, traveling during the rush hour, may be calculated in the form of equivalent variation measure $EV = e(p^0, u^1) - e(p^1, u^1)$, where $e(p,u)$ is the expenditure function, depending upon the price and utility levels. The functional form of consumer surplus is derived according to the travel demand functions (11) - (12) and is represented as (Minken and Samstad, 2000):

$$EV = \sum_i \sum_j B_{ij} \left[\left(\frac{\left(\dfrac{\beta_{ij}^{car}}{c_{ij}^{car^0}}\right)^{1/(1-\mu)} + \left(\dfrac{\beta_{ij}^{pub}}{c_{ij}^{pub^0} + t_{ij}^{pub}}\right)^{1/(1-\mu)}}{\left(\dfrac{\beta_{ij}^{car}}{c_{ij}^{car^1}}\right)^{1/(1-\mu)} + \left(\dfrac{\beta_{ij}^{pub}}{c_{ij}^{pub^1} + t_{ij}^{pub}}\right)^{1/(1-\mu)}} \right)^{(1-\mu)/\mu} - 1 \right] \qquad (13)$$

Travel demands of network users, traveling during other periods of the day except rush hour, are derived as a certain share of rush hour demands. Since there is no congestion during other periods of the day except rush hour, CS^{other} is derived as the sum of travel demands in other periods of the day multiplied with the difference in travel costs, which are due to implementation of infrastructure projects.

3.3. Calculation results

Calculations with the model are performed for the following four types of social welfare measures:

$$W_1 = CS + (1-\Phi)(OS^1 - OS^0) + p^{sh}\Phi(OS^1 - OS^0) + p^{sh}(RP^1 - RP^0) - (EC^1 - EC^0)$$

$$W_2 = CS + (OS^1 - OS^0) + (RP^1 - RP^0) - (EC^1 - EC^0)$$

$$W_3 = CS - (EC^1 - EC^0)$$

$$W_4 = CS$$

Calculated values are measured in 1000 NOK. Base case characteristics of transportation system are represented in Table 1, while calculated welfare measures and other indicators of infrastructure improvements are represented in Table 2.

Table 1. Base case characteristics of transportation system in 1000 NOK

Base case characteristics	
operative surplus	365838.3
governmental revenue	180.746
external costs	37615.8
share of car transportation	0.635
total distance covered by cars (km)	435251
accessibility measure	1992.752
share of givernmental financing	0.5
shadow price of public funds	1.2

Table 2. Welfare measures and other indicators of infrastructure improvements in 1000 NOK

	Inf package 1	**Inf package 2**	**Inf package 3**	**Inf package 4**	**Inf package 5**
Doubled capacities for car links					
between nodes 53 and 52	yes	yes	no	yes	no
between nodes 52 and 51	yes	yes	no	yes	no
between nodes 48 and 49	yes	yes	no	yes	no
between nodes 33 and 32	yes	yes	no	no	yes
between nodes 51 and 49	yes	yes	no	no	yes
between nodes 51 and 50	yes	yes	no	no	yes
Increased frequences for lines					
line 3 = 5 vehicles per hour	yes	no	yes	yes	no
line 2 = 4 vehicles per hour	yes	no	yes	no	yes
line 5 = 4 vehicles per hour	yes	no	yes	no	yes
Calculation results					
rush hour consumer surplus	247331.8	132739.9	116122.8	113003.1	124910.8
other periods consumer surplus	766519.9	105940.9	690360.5	121510.2	685598.5
operative surplus	363676.3	356084.8	373165.7	358935.8	371300.2
governmental revenue	178.651	180.746	178.651	178.651	180.746
external costs	36658.16	37815.47	36513.52	39484.57	3466.33
share of car transportation	0.635	0.643	0.627	0.64	0.629
total distance covered by cars (km)	438941	452914	422005	457798	414898
accessibility measure	2156.391	2081.749	2074.484	2067.793	2078.706
Social welfare measures					
social welfare 1	1012428.626	227752.28	815643.206	225049.266	850666.86
social welfare 2	1012645.245	228727.63	814910.885	225739.935	850120.67
social welfare 3	1014809.34	238481.13	807585.58	232644.53	844658.77
social welfare 4	1013851.7	238680.8	806483.3	234513.3	810509.3

Values in Table 2 are calculated according to the optimal car/passenger link flows that are the solution to network equilibrium problem (3)-(8) with improved transport infrastructure. Average solution time for the problem was 2 minutes. Accessibility measures for base situation and infrastructure investment packages are calculated according to the following formula (Pooler, 1995):

$$A = \sum_i \sum_j \left(D_{ij}^{car} \exp(-c_{ij}^{car}) + D_{ij}^{pub} \exp(-c_{ij}^{pub} - t_{ij}^{pub}) \right) \qquad (14)$$

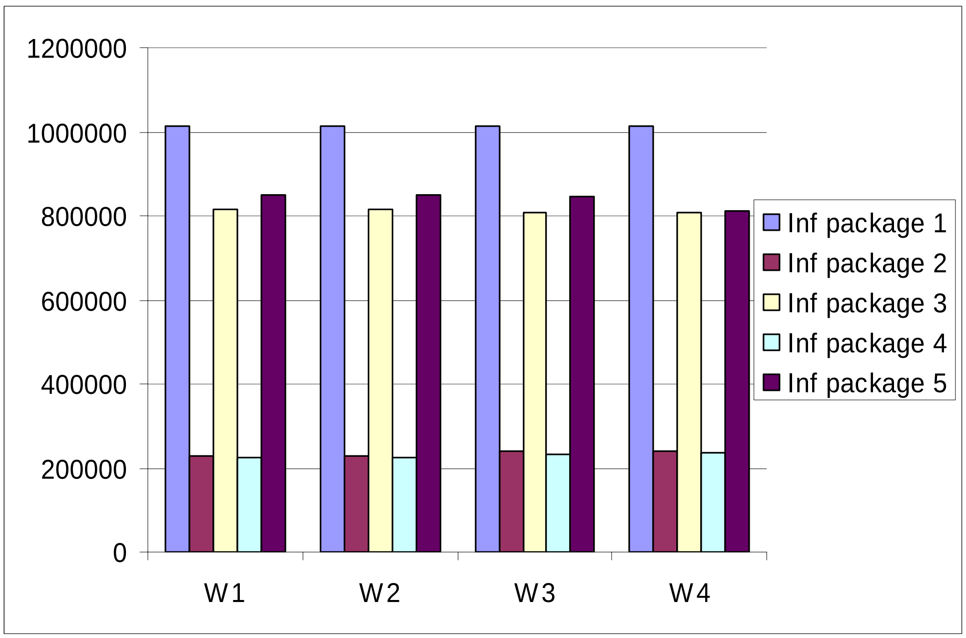

Figure 1. Welfare measures of infrastructure project packages in 1000 NOK

As demonstrated at Figure 1 the four functional forms of welfare measures used for the analysis result in the same ordering of infrastructure packages, with the values of welfare measures being slightly different for different formulations. Moreover the ordering of infrastructure packages according to the welfare measures is consistent with their ordering according to the accessibility measures (Table 2).

4. Concluding remarks

The model presented in the paper has demonstrated the way to formulate the network design problem with elastic travel demands and simultaneous equilibrium on both car and public transport networks. The model makes it is possible for a transport ministry to calculate welfare measures for combinations car road and public transport projects. Elastic travel demands allow one to account for substitutability between traveling by car and by public transport inside a city. Since travel demand functions have CES form it is much easier to estimate their parameters then those for probit or logit functional forms. It is then possible to implement the model under the tight time and resource constraints. Presented model is rather suitable for small cities, that need to perform analysis of infrastructure investment projects, but do not have large transport models and resources to build them.

The network equilibrium for traveling inside a city is formulated in the form of the Mixed Complementarity Problem (MCP), which allows for finding simultaneous solution of both car network and public transport network equilibriums. The formulation in MCP form gives one possibility to integrate the network equilibrium into bi-level programming framework using such modeling systems as GAMS, Mathematica and Matlab. Hence, a transport ministry is able to consider all combinations of possible infrastructure investments, which increases probability that the chosen variant is close to the ultimate optimum. Another advantage of the formulation in the form of MCP is the possibility to use travel demand functions directly in the equilibrium formulation. The formulation of network equilibrium in the MCP form may also be easily integrated with Spatial General Equilibrium models and land-use models, since they have the same functional form.

Based on the presented Oslo case-studio there is possible to give a number of recommendations to a transport ministry concerning the choice of social welfare functional form. Since the four different functional forms considered in the paper resulted in the same order of infrastructure packages, it is possible to state that the most important component of social welfare is the total consumer surplus of network users. Hence, it should be necessarily taken into account while analyzing infrastructure packages. Other elements of social welfare such as operative surplus and governmental revenue are not that important and may be neglected in case of low level of available informational details. Furthermore, the use of accessibility measure calculated according to (14) as the social welfare measure gives the same results as the use of other tested social welfare functional forms and hence may be recommended as an alternative welfare measure.

The model presented in the paper is a network equilibrium model and hence just incorporates effects that transport infrastructure improvements have at the level of network performance i.e. their direct effects. The welfare benefits calculated with the help of the presented model are not complete, since they do not capture any of the indirect effects that infrastructure improvements have on performance of a city. It does not account for any economic effects of new infrastructure and its effects upon freight transportation inside a city as well as upon locations of households and firms. In order to give more complete picture it is necessary to connect the model presented in the paper with the Spatial Computable General Equilibrium (SCGE) model of a city as well as with a freight network equilibrium model.

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Appendix to Chapter 2

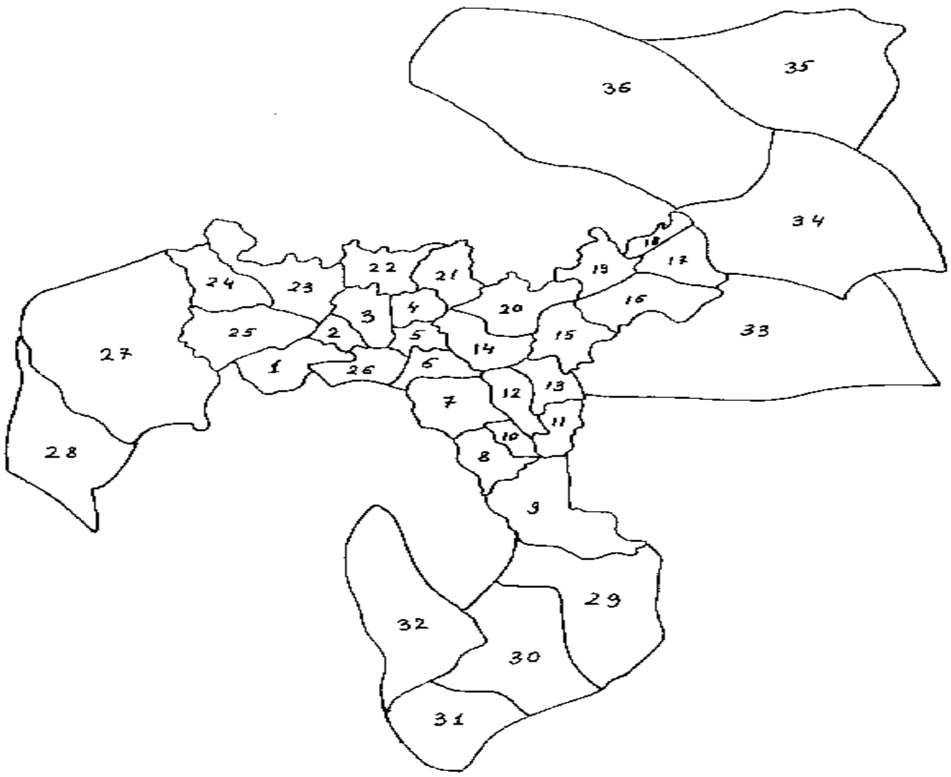

Figure 2. Travel zones used for the representation of Oslo/Akershus region

(1) Bygdøy-Frogner	(10) Lamberseter	(19) Grorud	(28) Asker
(2) Uranienborg-Majorstuen	(11) Bøler	(20) Bjerke	(29) Oppegard-Ski
(3) St.Hanshaugen-Ullevål	(12) Manglerud	(21) Grefsen-Kjelsås	(30) Ås
(4) Sagene-Torshov	(13) Østensjø	(22) Sogn	(31) Vestby
(5) Gruneløkka-Sofienberg	(14) Helsfyr-Sinsen	(23) Vinderen	(32) Nesodden-Frogn
(6) Gamle Oslo	(15) Hellerud	(24) Røa	(33) Lørenskog-Rælingen
(7) Ekeberg-Bekkelaget	(16) Furuset	(25) Ullern	(34) Skedsmo
(8) Nordstrand	(17) Stovner	(26) Sentrum	(35)Gjerdrum-Ullensaker
(9) Søndre Nordstrand	(18) Romsås	(27) Bærum	(36) Nittedal

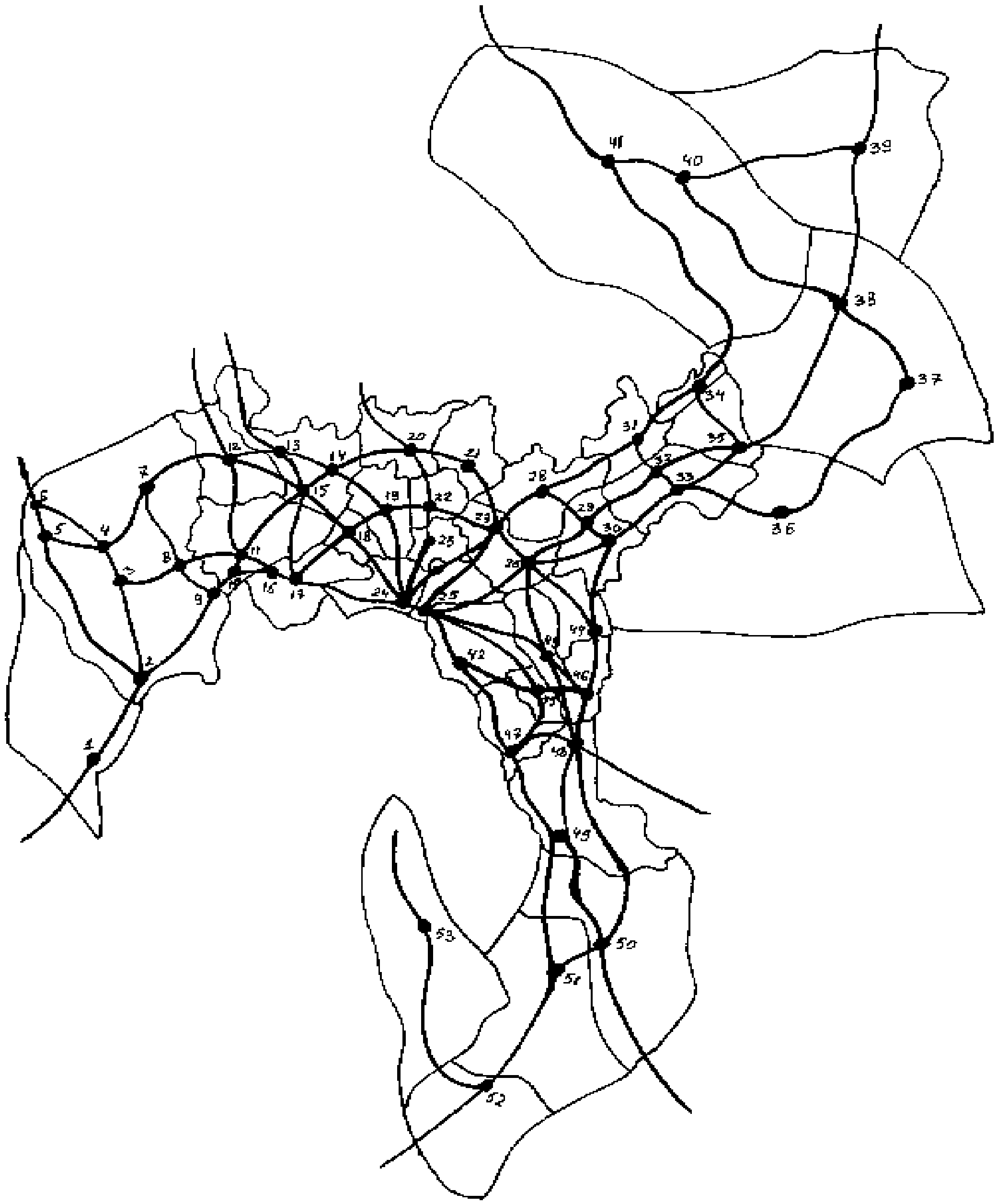

Figure 3. Structure of the car network in Oslo/Akershus region

Figure 4. Structure of the bus line in Oslo/Akershus region

Chapter 3

A Spatial General Equilibrium Model with explicit representation of transport network

In the recent years more and more attention is paid to the spatial nature of economy and as a consequence to the role of transport infrastructure in it. Hence, there is a clear need for a regional model explicitly representing spatial dimension in the form of transport network, as well as location decisions of households and firms. The present paper attempts to fill this gap by developing a regional Spatial General Equilibrium model with explicit transport network and congestion on it and endogenously determined employment and production locations. The model also incorporates different market imperfections such as market power of firms and transportation modes. A hypothetical example is used in order to prove functionality of the model and trace effects of infrastructure improvements on the performance of a region.

1. Introduction

This paper has two related goals. The first goal is to develop and present a regional Spatial Computable General Equilibrium (SCGE) model with explicit transport network and congestion on it, endogenously determined employment and production locations as well as representation of market power of firms and transport modes. Locations of firms and households' choices of employment locations are interrelated in the model and depend upon the structure and capacity of transport network. The second goal of the paper is to solve the constructed model in order to prove its functionality and investigate the role of transport infrastructure in regional economic development.

Development of the model presented in the paper is motivated by the fact that previously developed general equilibrium models, incorporating influence of transport infrastructure on regional performance, such as the models of Anas and Xu (1999), Brøcker (1998), Hussain (1996), Roson (1996) and Lederer (1989) do not account for all micro-level and regional level effects of infrastructure improvements. In some of them transport infrastructure is represented by exogenously given travel costs. Others do not consider allocation of employment and economic activities in a region. None of the models accounts for market imperfections such as market power of firms and transport modes and has explicit representation of real transport network, which are important parts of the model presented in the paper. Due to these missing parts previous analysis of the role of transport infrastructure in regional economic development cannot be considered to be complete and there is a need for the new type of regional model.

Generic SCGE model developed in the paper is based on SCGE model and network equilibrium model presented respectively in Ch 1 and Ch 2. The model developed in the paper not just combines the two models but develops them further by including imperfect competition on both market for production goods and market for transport services and adding location choice, housing market and land-use parts.

Transport infrastructure allows for communication between production/supply and consumption/demand activities in space. The influence of changes in infrastructure on economic performance of a region is rather complicated and many-sided. At each level of consideration: micro-level, regional level and macro-level, different effects are in place.

At micro-level, transport as one of the factors of production represents costs to individual businesses. Reduction in transportation costs enables firms to sell their products more cheaply. This stimulates greater demand leading to further cost-reduction and so on.

At regional level, improvements of transport infrastructure reduce trade barriers between regions and may promote economic growth in regions characterized by underutilization of a range of resources such as labor and land. Transport improvements are often seen as a way of unlocking these resources. Removing barriers to trade can also be seen as important to other, wider areas.

Poor transport link between one region and another can protect uncompetitive firms, enabling them to charge prices higher than efficient ones. Removing that effective barrier through improved transport links could benefit a wider regional economy by reducing prices to end households and producers. Transport improvements can also harm regional economy, by exposing indigenous firms to competition from stronger rivals outside an area. Where improved transport links behave in a way similar to the removal or reduction of a trade barrier, there can be winners and losers from the improvement, depending, among other things, on the structure of local and regional economies.

The size and structure of transport network influence the size of labor markets on the regional level through the value of time spent on commuting. One aspect of this relationship is that the time spent on commuting reduces labor endowments of households. Another is that households choose location of their jobs taking into account a number of factors including the time of commuting. If an infrastructure connecting a particular location of production activities with residential locations has been improved then more households will choose this production location as their job location.

Transportation is performed by several types of transport modes. The transport modes compete with each other on the market and the pattern of this competition depends upon an infrastructure available at a given moment. This is due to the fact that each transport mode uses infrastructure specific for it. Hence, the mode with the best infrastructure has competitive advantages over the others.

At macro-level investments into transport infrastructure are argued to have positive effect on GDP since they raise amount of capital stock for an economy and hence it's productive potential. Another argument is that better transport network leads to increased accessibility and hence efficient allocation of resources in an economy.

Generic SCGE model presented in the paper attempts to capture most of micro-level and regional-level effects of transport infrastructure on regional economic development, by combining representations of regional economy, location decisions of firms and households, market imperfections and real transport network.

In the model presented in the paper, consumption and production activities are attached to locations connected by a transport network. Demand and supply of labor are also spatially distributed. Households choose employment locations and amount of labor to supply according to the utility maximization principle. Transport network and congestion are explicitly incorporated into the model. Freight transportation is performed by several transport modes with different market power. Prices of transport services are the result of interaction between supply and demand sides of transportation market. Production firms are also supposed to have different market power and respectively the structure of transport network influences the level of competition between them. All activities in an economy are driven by available technology and total endowment of labor.

The paper is organized as follows. In Section 2 general description of the model is given. In Section 3 structure and mathematical formulation of the model are presented. In Section 4 a simple simulation exercise is performed in order to illustrate the way of implementing the model for an empirical analysis, while deriving the effects of particular transport infrastructure improvements on the economy of the region. Section 5 concludes the paper.

2. General description of the model

The model gives representation of a regional economic system in Spatial General Equilibrium (SGE) framework. Production/supply and consumption/demand activities are performed in space represented by a real transport network. Residential locations of households and locations production activities correspond to nodes of the transport network. Households choose an optimal residence-job pair of locations in order to maximize their utility functions. The levels of production at locations of production activities and the levels of consumption at residential locations are defined by location choices of households.

The model represents a region as consisting of a number of locations. All locations are divided into residential and production locations. Residential locations correspond to locations of households, while production locations correspond to locations of firms. Residential and production locations are connected by transport network, representing spatial dimension of the model, and are considered as its nodes.

Regional transport network consists of a number of nodes and links connecting them. Nodes of the transport network may be either locations or transition nodes referring to points in space where a transport carrier has to change a road and/or a mode of transportation. The regional transport network is constituted of car network, public transport network and freight transport network. The three networks use the same nodes but differ with respect to links connecting them. Car network and public transport network are used for commuting trips of households between their residence-job pairs of locations, while freight transport network is used for transporting of goods between locations of the region.

Each location in the region shelters a number of economic agents. Each production location shelters a number of production sectors, each producing one specific type of good using labor, capital and all other goods as inputs according to their nested CES production functions. Produced goods are further either consumed inside the location or transported to other residential or production locations inside the region for final consumption or intermediate use respectively. Transportation of goods to other locations is performed using transport services produced at the production location. A certain amounts of labor, capital and goods are used in the production process according to the transport sector nested CES production function. There is made no assumption about perfect competition in the model and the market power of each production sector at a particular location is represented by their non-competitive profit margin functions.

Each residential location shelters a number of households consuming goods, housing and leisure in amounts derived from the utility maximization problem under a certain budget restriction. It is supposed that all households residing at a particular location have the same nested CES utility function. Budgets of households consist of their wage and additional income in the form of revenue from total endowment of capital in the region, total endowments of housing at all residential locations and non-competitive profits of sectors that are distributed equally between households inside the region.

The number of households at a particular residential location is defined according to their location decisions. Each household in the region decides upon its pair of residence-job locations according to the indirect utility maximization principle. Its choice depends upon prices of goods and availability of housing at all residential locations, levels of wages at all production locations as well as upon commuting times between all residence-job pairs of locations that are the result of transport network performance. In the equilibrium, the total number of households is divided between residential locations in such a way that indirect utilities of households at the locations are equal.

Economic activities at each production location are driven by the amount of labor supplied to this location and total endowment of capital in the region. The levels of labor supply at production locations as well as demands for traveling between all pairs of residence-job locations are the result of households' location choices.

Economic part of the model may be classified as a regional trade model incorporating transport costs. Since each residential and production location is considered to be a separate area engaging in trade with the others, markets for a particular type of good clear separately from one another at each location of the region. Markets for labor and for housing also clear separately at each production and residential location respectively. Capital, on the other hand, is supplied at the level of entire region and hence its market clears at the regional level. Transport services also have a regional character and are supplied and demanded at the level of entire region.

Trade between locations of the region is performed according to the so-called "pooling concept". According to this concept, all goods of the same type, produced at various production locations and transported to a specific residential or production location for intermediate or final use, are first merged into a location specific pool of this commodity, from where they are delivered to intermediate or final users at the location. Hence, conceptually there is a distinction between a good produced at the location and the same type of good transported to the location. Moreover there is a distinction between producer and consumer prices of any particular good, since consumer price includes transportation costs.

Transport agents, operating at each location of the region, represent the pools of all goods at it. Each location specific transport agent corresponds to a particular type of good so that the total number of goods equals the total number of transport agents operating at a location. A transport agent is responsible for transporting its particular good from all production locations in the region using transport services and for merging them into a pool according to a specific production technology. Production functions of transport agents are of CES functional form, where the transport services are used in fixed proportions to the transported amounts of goods and there is a high degree of substitutability between goods of the same type produced at different production locations. This means that transport agents may easily substitute a particular type of good produced at one production location with the same type produced at another production location if the later is cheaper to buy or to transport.

While choosing the optimal mix of goods from different production locations, transport agents take into account not only monetary costs of freight transport but also such non-monetary costs as travel time and quality of transportation. These costs are not incorporated into consumer prices but influence the chosen mix of goods. Transport agents may be interpreted both as wholesalers and as an instrument representing market equilibrium for a particular type of good at the location.

All transport services in the region are produced by the regional transport sector, which uses labor, capital and goods, produced at different locations, as inputs according to its CES production function. Prices of transport services are the result of equilibrium at the transport market and depend not only upon production technology of the transport sector, but also upon the market power of different transport modes and upon the level of competition between them.

Economic part of the model is closely related with its network performance part. Location decisions of households define commuting travel demands between all residence-job pairs of locations, while trade flows from production locations to all locations inside the region define freight transport demands. Both commuting travel demands and freight transport demands are inputs to network performance part of the model consisting of car network equilibrium, public transport network equilibrium and freight transport network equilibrium.

Car and public transport network equilibria represent the optimal route choices of households and allow for deriving commuting times for all residence-job pairs of locations. The transport system is in equilibrium when each network user chooses a route with the smallest transport costs given the route choices of all other users. None of network users finds it worthwhile to deviate from his equilibrium route, if others do not deviate. Freight transport network equilibrium represents not only optimal route choices for freight carriers but also the competition between transport modes and allows for deriving generalized costs of transportation between locations that include both non-competitive profit margins of transport agencies and qualitative transport costs in monetary value. It is supposed that car and freight networks may be congested and levels of congestion on them depend upon the values of transport flows and structures of the networks.

The regional economic system is in equilibrium, when households' indirect utilities are equal for all pairs of resident-job locations; households' budgets are fully spent on consumption of goods, leisure and housing; total labour, capital and housing endowments in the region are fully utilized; prices of production goods equal marginal costs of the sectors plus their non-competitive profit margins; prices of consumption goods are set in such a way that none of transport agents receive positive profits; prices of transportation services equal marginal costs of the transport sectors plus non-competitive profit margins of transport modes; each network user chooses a route with the smallest transport costs (in the form of time cost or monetary costs) given the route choices of all other users and none of them finds it worthwhile to deviate from his equilibrium route, if others do not deviate.

The model consists of following related parts: SCGE part, location choice part, car network equilibrium part, public transport network equilibrium part and freight transport network equilibrium part. Connection between different parts of the model is performed through transportation demands, which are derived in SCGE and location choice parts and are inputs to network equilibrium parts, as well as through commuting times and prices of freight transport services, which are derived in network equilibrium parts and are inputs to location choice and SCGE parts, respectively. It should be noted that all parts of the model are solved simultaneously and formulated in the form of single mathematical problem.

Mathematical formulation of the model is based on the idea of integrating freight network equilibrium model with SCGE model proposed by Friesz (1996). He demonstrated the possibility to formulate the two models in the same mathematical form, which gives the possibility to solve them simultaneously. Both freight network equilibrium and general equilibrium are formulated in the form of Mixed Complementarity Problems (MCP) that have the following mathematical form: $F(X) \geq 0 \perp X \geq 0$ where X is the vector of variables, $F(\cdot)$ is the operator and $\perp$ means orthogonal, that is if $X = 0$ then $F(X) > 0$ and alternatively if $X > 0$ then $F(X) = 0$.

The model presented in the paper develops Friesz's idea by considering car network and public network equilibria formulated in MCP form in addition to freight network equilibrium. It also elaborates on formulation of SCGE part of the model, which in its mathematical formulation is similar to the one proposed by Hussain (1996). The model further integrates general equilibrium and network equilibrium parts of the model with land-use and location-choice parts, which are formulated similar to Anas and Xu (1999). In summary, the model presented in the paper combines most up-to-date ideas in regional and transport economics modelling and elaborates them in order to develop an integrated model of regional economy and transport infrastructure.

3. Mathematical formulation of the model

3.1. The setting

The model describes regional economic system in spatial equilibrium framework. Interactions between economic agents are performed in space, which is represented by real transport network. The transport network consists of nodes and links connecting them. All nodes of the transport network are divided into location nodes and transition nodes. Location nodes refer to residential locations of households or locations of production activities in the region, while transition nodes refer to points in space where a carrier has to change a road and/or a mode of transportation. There are in total R residential and P production locations, so that residential location index $i \in I^* = \{1,..., R\}$ and production location index $j \in J^* = \{R+1,..., R+P\}$. There exist also T transition locations and overall location index $n \in N^* = \{1,..., R+P+T\}$. There are S different types of production sectors in the economy, each producing one specific good $s \in S^* = \{1,..., S\}$ using labor, capital and intermediate goods as inputs.

3.2. Representative households

Total population P of the region is divided between all possible residence-job pairs of locations. Each residence-job pair *(i,j)* is associated with the following nested CES utility function $U_{ij} = \left(\alpha_u \left[\sum_{s \in S^*} a_s^u X_{ijs}^{\rho_u^c} \right]^{\frac{\rho_u}{\rho_u^c}} + \beta_u \left(L_{ij}^u \right)^{\rho_u} + \gamma_u \left(R_{ij} \right)^{\rho_u} \right)^{\frac{1}{\rho_u}}$ which is maximized by a household under the budget constraint

$$I_{ij} = \left(1 - \frac{t_{ij}}{h}\right) w_j + \frac{\overline{K} r}{P} + \frac{1}{P} \sum_{i \in I^*} \overline{R}_i h_i + \frac{1}{P} \sum_{j \in J^*} \sum_{s \in S^*} y_{js}^{pr} \varepsilon_{js} = \sum_{s \in S^*} X_{ijs} q_{is} + L_{ij}^U w_j + R_{ij} h_i ,$$

where $\alpha_u, \beta_u, \gamma_u > 0$ such that $\alpha_u + \beta_u + \gamma_u = 1$ are the share parameters . The elasticity of substitution between consumption goods is determined as $\sigma_u^c = \dfrac{1}{1-\rho_u^c}$ and the elasticity of substitution between leisure, housing and composite consumption good is determined as $\sigma_u = \dfrac{1}{1-\rho_u}$ where $0 < \rho_u^c < 1$, $0 < \rho_u < 1$ and $\sigma_u^c < \sigma_u$.

The total budget of household choosing to reside at the location *i* and work at the location *j* consists of wage w_j and additional income in the form of revenue from total endowment of capital in the region $\overline{K}$, total endowments of housing $\overline{R}_i$ at residential locations and non-competitive profits of sectors $y_{js}^{pr}\varepsilon_{js}$, which is equally distributed between all households inside the region. Each household spends its entire budget on consumption of goods in amounts X_{ijs}, housing in amount R_{ij} as well as on leisure and residence-job commuting trips. L_{ij}^U is the demand for leisure, representing the share of wage w_j, which could be received if a person used his total labor endowment per day corresponding to *h = 16* hours on working. $t_{ij} = 0.5(c_{ij}^{car} + c_{ij}^{col})$ is the average time costs of traveling from residential location *i* to job location *j* by car or by public transport measured in hours. Marshalian demands of the household are:

$$L_{ij}^U\left(I_{ij}, w_j, h_i, \{q_{is}\}_{s\in S^*}\right) = I_{ij}\left(\frac{\beta_u}{w_j}\right)^{\sigma_u}\left(\alpha_u^{\sigma_u}\left[\sum_{s\in S^*}\left(a_s^u\right)^{\sigma_u^c} q_{is}^{1-\sigma_u^c}\right]^{\frac{1-\sigma_u}{1-\sigma_u^c}} + \beta_u^{\sigma_u} w_j^{1-\sigma_u} + \gamma_u^{\sigma_u} h_i^{1-\sigma_u}\right)^{-1}$$

$$R_{ij}\left(I_{ij}, w_j, h_i, \{q_{is}\}_{s\in S^*}\right) = I_{ij}\left(\frac{\gamma_u}{h_i}\right)^{\sigma_u}\left(\alpha_u^{\sigma_u}\left[\sum_{s\in S^*}\left(a_s^u\right)^{\sigma_u^c} q_{is}^{1-\sigma_u^c}\right]^{\frac{1-\sigma_u}{1-\sigma_u^c}} + \beta_u^{\sigma_u} w_j^{1-\sigma_u} + \gamma_u^{\sigma_u} h_i^{1-\sigma_u}\right)^{-1}$$

$$X_{ijs}\left(I_{ij}, w_j, h_i, \{q_{is}\}_{s\in S^*}\right) = \left(1 - L_{ij}^u - R_{ij}\right) I_{ij}\left(\frac{a_s^u}{q_{is}}\right)^{\sigma_u^c}\left[\sum_{s'\in S^*}\left(a_{s'}^u\right)^{\sigma_u^c} q_{is'}^{1-\sigma_u^c}\right]^{-1}$$

Indirect utility function associated with these demands is:

$$V_{ij}\left(I_{ij}, w_j, h_i, \{q_{is}\}_{s\in S^*}\right) = I_{ij}\left(\alpha_u^{\sigma_u}\left[\sum_{s\in S^*}\left(a_s^u\right)^{\sigma_u^c} q_{is}^{1-\sigma_u^c}\right]^{\frac{1-\sigma_u}{1-\sigma_u^c}} + \beta_u^{\sigma_u} w_j^{1-\sigma_u} + \gamma_u^{\sigma_u} h_i^{1-\sigma_u}\right)^{\frac{1}{\sigma_u - 1}}$$

The household's choice of residence-job pair is performed according to the logit discrete choice model, so that the share of population choosing the residence-job pair *(i,j)* is calculated as $\Psi_{ij} = \dfrac{\exp(V_{ij})}{\sum_{j' \in J^*} \exp(V_{ij'})}$ and $\sum_{j \in J^*} \Psi_{ij} = 1$.

3.3. Production sectors

There are S types of production sectors in the region each producing only one type of good. The technology of sectors is of nested CES type with labor, capital and intermediate goods used as inputs. Production sectors of the same type have the same production technology irrespective of their location, where production function for the sector of type s at the location j is:

$$y_{js}^{pr} = \theta_s \left(\alpha_s L_{js}^{\rho_s} + \beta_s K_{js}^{\rho_s} + \gamma_s \left[\sum_{s' \in S^*} a_{ss'} Z_{jss'}^{\rho_s^c} \right]^{\frac{\rho_s}{\rho_s^c}} \right)^{\frac{1}{\rho_s}} \text{ where}$$

$\theta_s > 0$ is the scale parameter for sector s, $\alpha_s, \beta_s, \gamma_s > 0$ where $\alpha_s + \beta_s + \gamma_s = 1$ and $a_{ss'} > 0$ where $\sum_{s' \in S} a_{ss'} = 1$ are the share parameters of the function. The elasticity of substitution between the intermediate goods is defined as $\sigma_s = \dfrac{1}{1-\rho_s}$ and the elasticity of substitution between labor, capital and the composite intermediate good is defined as $\sigma_s^c = \dfrac{1}{1-\rho_s^c}$ where $0 < \rho_s^c < 1$, $0 < \rho_s < 1$ and $\sigma_s^c < \sigma_s$.

y_{js}^{pr} is the output of sector s at the location j, L_{js} and K_{js} are the inputs of labor and capital for the sector and $Z_{jss'}$ is the input of intermediate good s'. Conditional input demand functions for the sectors are:

$$L_{js}\left(y_{js}^{pr}, w_j, r, \{q_{js}\}_{s \in S^*}\right) = \left(\frac{y_{js}^{pr}}{\theta_s}\right) \left(\alpha_s \left(\alpha_s^{\sigma_s} w_j^{1-\sigma_s} + \beta_s^{\sigma_s} r^{1-\sigma_s} + \gamma_s^{\sigma_s} \left[\sum_{s' \in S^*} a_{ss'}^{\sigma_s^c} q_{js'}^{1-\sigma_s^c} \right]^{\frac{1-\sigma_s}{1-\sigma_s^c}} \right) \right)^{\sigma_s} w_j^{-\sigma_s},$$

$$K_{js}\left(y_{js}^{pr}, w_j, r, \{q_{js}\}_{s\in S^*}\right) = \left(\frac{y_{js}^{pr}}{\theta_s}\right)\left(\beta_s\left(\alpha_s^{\sigma_s} w_j^{1-\sigma_s} + \beta_s^{\sigma_s} r^{1-\sigma_s} + \gamma_s^{\sigma_s}\left[\sum_{s'\in S^*} a_{ss'}^{\sigma_s^c} q_{js'}^{1-\sigma_s^c}\right]^{\frac{1-\sigma_s}{1-\sigma_s^c}}\right)\right)^{\sigma_s} r^{-\sigma_s}$$

$$Z_{jss'}\left(y_{js}^{pr}, w_j, r, \{q_{js}\}_{s\in S^*}\right) =$$

$$\left(\frac{y_{js}^{pr}}{\theta_s}\right)\left(\gamma_s\left(\alpha_s^{\sigma_s} w_j^{1-\sigma_s} + \beta_s^{\sigma_s} r^{1-\sigma_s} + \gamma_s^{\sigma_s}\left[\sum_{s''\in S^*} a_{ss''}^{\sigma_s^c} q_{js''}^{1-\sigma_s^c}\right]^{\frac{1-\sigma_s}{1-\sigma_s^c}}\right)\right)^{\sigma_s}\left(\frac{a_{ss'}}{q_{js'}}\right)^{\sigma_s^c}\left(\sum_{s''\in S^*} a_{ss''}^{\sigma_s^c} q_{js''}^{1-\sigma_s^c}\right)^{\frac{\sigma_s^c-\sigma_s}{1-\sigma_s^c}}$$

There is made no assumption about the presence of perfect competition in the regional economy. Hence, any production sector at a location may possess a market power represented by its non-competitive profit margin. In case, when a sector is perfectly competitive, its profit margin is equal to zero. The profit margin is an increasing function of demand. Since in market equilibrium demand equals supply, one may reformulate the profit margin as depending upon the level of production of a sector in the following form $\varepsilon_{js}\left(y_{js}^{pr}\right)$. The equilibrium profit condition for the production sector *s* at the location *j* is the following:

$$\frac{1}{\theta_s}\left(\alpha_s^{\sigma_s} w_j^{1-\sigma_s} + \beta_s^{\sigma_s} r^{1-\sigma_s} + \gamma_s^{\sigma_s}\left[\sum_{s'\in S^*} a_{ss'}^{\sigma_s^c} q_{js'}^{1-\sigma_s^c}\right]^{\frac{1-\sigma_s}{1-\sigma_s^c}}\right)^{\frac{1}{1-\sigma_s}} + \varepsilon_{js}\left(y_{js}^{pr}\right) - p_{js} \geq 0 \perp y_{js}^{pr} \geq 0 \qquad (1)$$

for $j \in J^*, s \in S^*$ where p_{js} is equilibrium price of good produced by sector *s* (good of type *s*) at the location *j*.

3.4. Transport agents

Transport agents are responsible for transportation of goods to the locations of households or production activities and may be thought of as wholesalers. At each location *k* there are *S* such agents each transporting one specific type of good from the locations of production activities using transport services. A transport agent uses goods of a specific type produced at all production locations and transport services according to the nested CES technology. It is supposed that in order to transport one unit of good *s* a transport agent needs $\frac{1}{\nu_s}$ units of transport service, which means that transport services are used in some fixed proportion to the amounts of transported goods.

The technology of transport agent s at location k is represented by the following production function:

$$y_{ks}^{ta} = \theta_{ks}^{ta}\left[a_{kks}^{ta}\left(G_{kks}\right)^{\rho_s^{ta}} + \sum_{\substack{j\in J^* \\ j\neq k}} a_{jks}^{ta} \min\left\{G_{jks}, \nu_s T_{jks}\right\}^{\rho_s^{ta}}\right]^{1/\rho_s^{ta}}$$

where $\theta_{ks}^{ta} > 0$ is the scale parameter and the elasticity of substitution between inputs is calculated as $\sigma_s^{ta} = \frac{1}{1-\rho_s^{ta}}$ where $0 < \rho_s^{ta} < 1$. y_{ks}^{ta} is the output of intermediate/consumption good s at the location k, G_{jks} is the input of good s produced at the location j, T_{jks} is the input of transportation service, consisting of transporting one unit of good s from the production location j to the location k , and $\nu_s > 1$ is the technological coefficient specific for each type of good. This production function tells us that in order to produce an intermediate/consumption good, a transport agent uses a mix of goods transported from different production locations in combination with transport services, where the proportions of this combination depend upon the coefficient ν_s specific for each type of good. In case, when transport agent uses the good produced at its own production location, no transportation services are needed.

When choosing the optimal mix of goods, transported from different production locations, a transport agent takes into account not only monetary price of transport services but also their non-monetary characteristics such as travel time costs and quality of transportation. These non-monetary characteristics are summaries in the form of generalized travel costs c_{ij}, which are the result of freight network performance. These costs are not included into the consumption price of a good, but taken into account while choosing the optimal mix. Conditional input demand functions for the transport agents are:

$$G_{jks}\left(y_{ks}^{ta},\{p_{js}\}_{j\in J^*},\{f_{jk}\}_{j\in J^*}\right)=$$

$$\left(\frac{y_{ks}^{ta}}{\theta_{ks}^{ta}}\right)\left(a_{jks}^{ta}\left[\left(a_{kks}^{ta}\right)^{\sigma_s^{ta}}\left(p_{ks}\right)^{1-\sigma_s^{ta}}+\sum_{\substack{j'\in J^*\\ j'\neq k}}\left(a_{j'ks}^{ta}\right)^{\sigma_s^{ta}}\left(p_{j's}+\frac{1}{\nu_s}(f_{j'k}+c_{j'k})\right)^{1-\sigma_s^{ta}}\right]^{\frac{1}{1-\sigma_s^{ta}}}\right)^{\sigma_s^{ta}}\left(p_{js}+\frac{1}{\nu_s}(f_{jk}+c_{jk})\right)^{-\sigma_s^{ta}}$$

$$G_{kks}\left(y_{ks}^{ta},\{p_{js}\}_{j\in J^*},\{f_{jk}\}_{j\in J^*}\right)=$$

$$\left(\frac{y_{ks}^{ta}}{\theta_{ks}^{ta}}\right)\left(a_{kks}^{ta}\left[\left(a_{kks}^{ta}\right)^{\sigma_s^{ta}}\left(p_{ks}\right)^{1-\sigma_s^{ta}}+\sum_{\substack{j'\in J^*\\ j'\neq k}}\left(a_{j'ks}^{ta}\right)^{\sigma_s^{ta}}\left(p_{j's}+\frac{1}{\nu_s}(f_{j'k}+c_{j'k})\right)^{1-\sigma_s^{ta}}\right]^{\frac{1}{1-\sigma_s^{ta}}}\right)^{\sigma_s^{ta}}\left(p_{ks})\right)^{-\sigma_s^{ta}}$$

and $T_{jks}\left(y_{ks}^{ta},\{p_{js}\}_{j\in J^*},\{f_{jk}\}_{j\in J^*}\right)=\frac{1}{\nu_s}G_{jks}$ for $j\neq k$, where f_{jk} is the equilibrium price of freight transportation service, consisting of transporting one unit of good from the location of production activities *j* to the location *k*. Equilibrium profit condition for the transport agents is: $\frac{1}{\theta_{ks}^{ta}}\left[\left(a_{kks}^{ta}\right)^{\sigma_s^{ta}}\left(p_{ks}\right)^{1-\sigma_s^{ta}}+\sum_{\substack{j\in J^*\\ j\neq k}}\left(a_{jks}^{ta}\right)^{\sigma_s^{ta}}\left(p_{js}+\frac{1}{\nu_s}f_{jk}\right)^{1-\sigma_s^{ta}}\right]^{\frac{1}{1-\sigma_s^{ta}}}-q_{ks}\geq 0\perp y_{ks}^{ta}\geq 0$

(2) for $k\in K^*, s\in S^*$

3.5. Transport sector

The transport sector produces all transport services in the region. It is supposed that some particular part of these services is produced at each location of production activities using location specific labor, capital and intermediate goods as inputs according to the nested CES production technology: $y_{jk}^{tr}=\theta_{tr}\left(\alpha_{tr}\left(L_{jk}^{tr}\right)^{\rho_{tr}}+\beta_{tr}\left(K_{jk}^{tr}\right)^{\rho_{tr}}+\gamma_{tr}\left[\sum_{s\in S^*}a_s^{tr}Q_{jks}^{\rho_{tr}^c}\right]^{\frac{\rho_{tr}}{\rho_{tr}^c}}\right)^{\frac{1}{\rho_{tr}}}$ for $j\neq k$, where $\theta_{tr}>0$ is the scale parameter $\alpha_{tr},\beta_{tr},\gamma_{tr}>0$ where $\alpha_{tr}+\beta_{tr}+\gamma_{tr}=1$, and $a_s^{tr}>0$ where $\sum_{s\in S^*}a_s^{tr}=1$. The elasticity of substitution between intermediate goods is determined as $\sigma_{tr} = \frac{1}{1-\rho_{tr}}$ and the elasticity of substitution between labor, capital and composite intermediate good is determined as $\sigma_{tr}^{c} = \frac{1}{1-\rho_{tr}^{c}}$,where $0 < \rho_{tr}^{c} < 1, 0 < \rho_{tr} < 1$ and $\sigma_{tr}^{c} < \sigma_{tr}$. y_{jk}^{tr} is the output of transportation from the location of production activities j to the location k, produced at the location j. L_{jk}^{tr} and K_{jk}^{tr} are labor and capital inputs respectively and Q_{jks} is the input of intermediate good s. Conditional input demand functions for the transport sector are:

$$L_{jk}^{tr}\left(y_{jk}^{tr}, w_j, r, \{q_{js}\}_{s\in S^*}\right) = \left(\frac{y_{jk}^{tr}}{\theta_{tr}}\right)\left(\alpha_{tr}\left(\alpha_{tr}^{\sigma_{tr}} w_j^{1-\sigma_{tr}} + \beta_{tr}^{\sigma_{tr}} r^{1-\sigma_{tr}} + \gamma_{tr}^{\sigma_{tr}}\left[\sum_{s'\in S^*}\left(a_{s'}^{tr}\right)^{\sigma_{tr}^c} q_{js'}^{1-\sigma_{tr}^c}\right]^{\frac{1-\sigma_{tr}}{1-\sigma_{tr}^c}}\right)\right)^{\sigma_{tr}} w_j^{-\sigma_{tr}}$$

$$K_{jk}^{tr}\left(y_{jk}^{tr}, w_j, r, \{q_{js}\}_{s\in S^*}\right) = \left(\frac{y_{jk}^{tr}}{\theta_{tr}}\right)\left(\beta_{tr}\left(\alpha_{tr}^{\sigma_{tr}} w_j^{1-\sigma_{tr}} + \beta_{tr}^{\sigma_{tr}} r^{1-\sigma_{tr}} + \gamma_{tr}^{\sigma_{tr}}\left[\sum_{s'\in S^*}\left(a_{s'}^{tr}\right)^{\sigma_{tr}^c} q_{js'}^{1-\sigma_{tr}^c}\right]^{\frac{1-\sigma_{tr}}{1-\sigma_{tr}^c}}\right)\right)^{\sigma_{tr}} r^{-\sigma_{tr}}$$

$$Q_{jks}\left(y_{jk}^{tr}, w_j, r, \{q_{js}\}_{s\in S^*}\right) =$$
$$\left(\frac{y_{jk}^{tr}}{\theta_{tr}}\right)\left(\gamma_{tr}\left(\alpha_{tr}^{\sigma_{tr}} w_j^{1-\sigma_{tr}} + \beta_{tr}^{\sigma_{trs}} r^{1-\sigma_{tr}} + \gamma_{tr}^{\sigma_{trs}}\left[\sum_{s'\in S^*}\left(a_{s'}^{tr}\right)^{\sigma_{tr}^c} q_{js'}^{1-\sigma_{tr}^c}\right]^{\frac{1-\sigma_{tr}}{1-\sigma_{tr}^c}}\right)\right)^{\sigma_{tr}} \left(\frac{a_s^{tr}}{q_{js}}\right)^{\sigma_{tr}^c} \left(\sum_{s'\in S^*}\left(a_{s'}^{tr}\right)^{\sigma_{tr}^c} q_{js'}^{1-\sigma_{tr}^c}\right)^{\frac{\sigma_{tr}^c-\sigma_{tr}}{1-\sigma_{tr}^c}}$$

The equilibrium profit condition for this sector is the following:

$$\frac{1}{\theta_{tr}}\left(\alpha_{tr}^{\sigma_{trs}} w_j^{1-\sigma_{tr}} + \beta_{tr}^{\sigma_{tr}} r^{1-\sigma_{tr}} + \gamma_{tr}^{\sigma_{tr}}\left[\sum_{s'\in S^*}\left(a_{s'}^{tr}\right)^{\sigma_{tr}^c} q_{js'}^{1-\sigma_{tr}^c}\right]^{\frac{1-\sigma_{tr}}{1-\sigma_{tr}^c}}\right)^{\frac{1}{1-\sigma_{tr}}} - f_{jk} \geq 0 \perp y_{jk}^{tr} \geq 0 \qquad (3)$$

for $j \in J^*, k \in K^*$

3.6. Equilibrium at the markets

At the equilibrium no commodity/factor is in excess demand and if it is, than the commodity/factor has zero price i.e. it is free commodity. These equilibrium conditions may be written in the following mathematical form:

- equilibrium at the labor market

$$P\sum_{i\in I^*}\Psi_{ij}\left(1-L_{ij}^u\left(I_{ij},w_j,h_i,\{q_{is}\}_{s\in S^*}\right)\right)-\sum_{s\in S^*}L_{js}\left(y_{js}^{pr},w_j,r,\{q_{js'}\}_{s'\in S^*}\right)- \sum_{k\in K^*}L_{jk}^{tr}\left(y_{jk}^{tr},w_j,r,\{q_{js}\}_{s\in S^*}\right)\geq 0\perp w_j\geq 0 \quad (4)$$

for $j\in J^*$

- equilibrium at the capital market

$$\bar{K}-\sum_{j\in J^*}\sum_{s\in S^*}K_{js}\left(y_{js}^{pr},w_j,r,\{q_{js'}\}_{s'\in S^*}\right)-\sum_{j\in J^*}\sum_{k\in K^*}K_{jk}^{tr}\left(y_{jk}^{tr},w_j,r,\{q_{js}\}_{s\in S^*}\right)\geq 0\perp r\geq 0 \quad (5)$$

- equilibrium at the housing market

$$\bar{R}_i-P\sum_{j\in J^*}\Psi_{ij}R_{ij}(I_{ij},w_j,h_i,\{q_{is}\}_{s\in S^*})\geq 0\perp h_i\geq 0 \quad (6)$$

- equilibrium at the market for consumption goods

$$y_{is}^{ta}-P\sum_{j\in J^*}\Psi_{ij}X_{ijs}\left(I_{ij},w_j,h_i,\{q_{is'}\}_{s'\in S^*}\right)\geq 0\perp q_{is}\geq 0 \text{ for } i\in I^*,s\in S^* \quad (7)$$

-equilibrium at the market for intermediate goods

$$y_{js}^{ta}-\sum_{s'\in S^*}Z_{js's}\left(y_{js'}^{pr},w_j,r,\{q_{js''}\}_{s''\in S^*}\right)-\sum_{k\in K^*}Q_{jks}\left(y_{jk}^{tr},w_j,r,\{q_{js'}\}_{s'\in S^*}\right)\geq 0\perp q_{js}\geq 0 \quad (8)$$

for $j\in J^*,s\in S^*$

- equilibrium at the market for production goods

$$y_{js}^{pr}-\sum_{k\in K^*}G_{jks}\left(y_{ks}^{ta},\{p_{j's}\}_{j'\in J^*},\{f_{j'k}\}_{j'\in J^*}\right)\geq 0\perp p_{js}\geq 0 \text{ for } j\in J^*,s\in S^* \quad (9)$$

- equilibrium at the market for transport services

$$y_{jk}^{tr}-\sum_{s\in S^*}T_{jks}\left(y_{ks}^{ta},\{p_{j's}\}_{j'\in J^*},\{f_{j'k}\}_{j'\in J^*}\right)\geq 0\perp f_{jk}\geq 0 \text{ for } j\in J^*,k\in K^* \quad (10)$$

3.7. Equilibrium at the car network

Supply and demand for labor in the economy are divided by space, which gives rise to the demand for transportation between any residence-job pair of locations. Households may use either car or public transport in order to commute between their residence and job locations. The choice of transport mode is performed according to the logit demand model, where $V_{ij}^{car} = \hat{V}_{ij} - c_{ij}^{car}$ and $V_{ij}^{pub} = \hat{V}_{ij} - c_{ij}^{pub}$ represent indirect utilities associated with choosing car mode and public transport mode respectively, while traveling between the residence-job pair *(i,j)*. $\hat{V}_{ij}$ is a constant representing indirect utility of choosing the residence-job pair *(i,j)* net of influence of travel time costs. c_{ij}^{car} and c_{ij}^{pub} are travel time costs for car transport mode and public transport mode respectively.

Given that the total amount of commuting between the residence-job pair *(i,j)* is calculated as $P \cdot \Psi_{ij}$, elastic demands for traveling by car and by public transport are (McFadden, 1973):

$$D_{ij}^{car}\left(c_{ij}^{car}, c_{ij}^{pub}\right) = P \cdot \Psi_{ij} \cdot \frac{\exp(V_{ij}^{car})}{\exp(V_{ij}^{car}) + \exp(V_{ij}^{pub})} = P \cdot \Psi_{ij} \cdot \frac{\exp(-c_{ij}^{car})}{\exp(-c_{ij}^{car}) + \exp(-c_{ij}^{pub})}$$

$$D_{ij}^{pub}\left(c_{ij}^{pub}, c_{ij}^{car}\right) = P \cdot \Psi_{ij} \cdot \frac{\exp(V_{ij}^{pub})}{\exp(V_{ij}^{car}) + \exp(V_{ij}^{pub})} = P \cdot \Psi_{ij} \cdot \frac{\exp(-c_{ij}^{pub})}{\exp(-c_{ij}^{car}) + \exp(-c_{ij}^{pub})}$$

Households traveling by car choose the shortest path on transport network, with respect to time of commuting. The travel time on each network link depends upon its length as well as upon level of congestion on the link. The total time of commuting is the sum of travel times on the links constructing the shortest path between the residence-job pair. Congestion levels of the network links are the result of interaction between car users and a certain share of freight transportation $0 < \pi < 1$, performed in the morning rush hour. Equilibrium at the car network is formulated in the following way:

$$\sum_{n \in N^*} x_{in}^j \delta_{in}^{car} - \sum_{n \in N^*} x_{ni}^j \delta_{ni}^{car} = D_{ij}^{car}\left(c_{ij}^{car}, c_{ij}^{pub}\right) \quad \text{for} \quad i \in I^*, \quad j \in J^* \tag{11}$$

$$c_{nm}^{car}(fc_{nm} + \pi \cdot fr_{nm}) + c_{mj}^{car} - c_{nj}^{car} \geq 0 \perp x_{nm}^j \geq 0 \tag{12}$$

where fr_{nm} is the total flow of freight transport on the link, $fc_{nm} = \sum_{j \in J^*} x_{nm}^j$ is the total flow of cars on the link, x_{nm}^j is the flow of cars on the link between the nodes n and m, with destination in the production location *j*, $\delta_{nm}^{car} \in \{0,1\}$ is the binary variable representing the structure of car network, which equals unity when there exists a car link between the nodes *n* and *m*. $c_{nm}^{car}(\cdot)$ is a travel time function on the link measured in hours.

3.8. Equilibrium at the public transport network

Public transport uses the separate transport network different from the one for car. This network consists of a number of links on those one may determine different transport lines $l \in L^*$ (bus lines, underground lines, train lines etc). Each link may be a part of only one transport line. If a number of different transport lines connect a pair of nodes, there should be one link for each of them. Each link is associated with constant in-vehicle time. This time depends upon the distance between the nodes and the type of public transport used on the link. While traveling on the public transport network, passengers have to change the public lines and hence they have to wait for a new line to come. At each node there is a certain set of lines that passengers can take and waiting times depend upon the type of line as well as upon the total flow of passengers using this line at the particular link. The higher are frequencies of the lines the lower are waiting times for passengers.

Equilibrium at the public transport network is formulated in the following way:

$$\sum_{n\in N^*}\sum_{l'\in L^*}\sum_{l\in L^*} y^{j}_{inl'l}\lambda^{l'l}_{in} - \sum_{n\in N^*}\sum_{l'\in L^*}\sum_{l\in L^*} y^{j}_{nil'l}\lambda^{l'l}_{ni} = D^{pub}_{ij}(c^{pub}_{ij}, c^{car}_{ij}) \text{ for } i \in I^*,\ j \in J^* \quad (13)$$

$$t_{nml} + v^{l'l}_{nm}(fp_{nml}) + c^{pub}_{mj} - c^{pub}_{nj} \geq 0 \perp y^{j}_{nml} \geq 0 \text{ for } n,m \in N^*,\ j \in J^* \quad (14)$$

$$fp_{nml} = \sum_{h\in N^*}\sum_{l'\in L^*} y^{h}_{nml'l} \text{ for } n,m \in N^*,\ l \in L^* \quad (15)$$

where $y^{j}_{nml'l}$ is the passenger flow to job destination j on link *(n,m)* of the line l, who change the line l' to line l at node n, $\lambda^{l'l}_{nm} = \max\{\max_{h\in N^*}\{\gamma^{l'}_{hn}\}, \gamma^{l}_{nm}\}$, where $\gamma^{l}_{nm} \in \{0,1\}$ is the binary variable representing the structure of public transport network. It equals unity if there exists a link between the pair of nodes *(n,m)* which is a part of line l and zero otherwise. Hence, variable $\lambda^{l'l}_{nm}$ equals unity, when there exists a possibility to change line l' to line l at node n and continue on the link to node m. t^{l}_{nm} is in vehicle travel time between a pair of nodes *(n,m)* using line l and $v^{l'l}_{nm}(\cdot)$ is the waiting time function, depending upon the total passenger flow fp_{nml} on the link between a pair of nodes *(n,m)*, which is a part of line l .The waiting functions also depend upon the frequencies of public lines f_l, measured in passengers per hour, that are fixed outside the model. The higher are the frequencies of public lines the lower are waiting times. $v^{l'l}_{nm}(\cdot)$ represents the waiting time for passengers, changing line l' to line l at node n and continuing on the link to node m.

3.9. Equilibrium at the freight network

Production and consumption activities in the region are divided by space, which gives rise to the demand for freight transport services. These services are provided by different transport modes $w \in W^*$ such as truck, train and boat. Each mode is thought of as a separate part of the market for transport services, with a number of firms operating on it. Each mode has specific competitive structure. Truck mode is usually fully competitive, while train and boat modes may be even monopolistic. The modes compete with each other for the consumers by setting prices for their services. Interactions between producers and consumers of transport services are performed on the freight transport network and equilibrium at the market as well as the network equilibrium is formulated in the following mathematical form:

$$\sum_{n \in N^*} y_{jn}^k \delta_{jn}^{fr} - \sum_{n \in N^*} y_{nj}^k \delta_{nj}^{fr} = \sum_{s \in S^*} G_{jks} \quad \text{for} \quad j \in J^*, k \in K^* \tag{16}$$

$$c_{nm}^{fr}(fr_{nm}) + \varepsilon_{nm}^{fr}(fr_{nm}) + c_{mh} - c_{nh} \geq 0 \perp y_{nm}^h \geq 0 \text{ where } fr_{nm} = \sum_{h \in N^*} y_{nm}^h \tag{17}$$

y_{nm}^h is the flow of freight transport on the link between the nodes n and m, with destination in node h, $\delta_{nm}^{fr} \in \{0,1\}$ is the binary variable representing the structure of the freight network. It equals unity if there exists a link between the nodes n and m and zero otherwise. $c_{nm}^{fr}(\cdot)$ is the costs of transportation on the link *(n,m)* positively depending upon the link travel time and hence upon the total flow of freight transport on the link fr_{nm}. The transportation cost function is measured in monetary units and represents the value of non-monetary costs of transportation such as travel time and quality of transportation between locations. $\varepsilon_{nm}^{fr}(\cdot)$ is the profit margin function on the link also measured in monetary units and depending upon the transport mode serving it.

Equations (1)-(17) constitute the generic SCGE model of the region, which incorporates implicit representation of transport network. The mathematical formulation of the generic SCGE model belongs to the wide class of mathematical problems called Mixed

Complementary Problems (MCP), which have the following general mathematical formulation: $F(X) \geq 0 \perp X \geq 0$, where X is the vector of variables, $F(\cdot)$ is the operator and $\perp$ means orthogonal, that is if $X = 0$ then $F(X) > 0$ and alternatively if $X > 0$ then $F(X) = 0$.

In the formulation of the generic SCGE model of the region (1)-(17) the following variables are unknown: $w_j, r, h_i, q_{ks}, p_{js}, f_{jk}, y_{ks}^{ta}, y_{js}^{pr}, y_{jk}^{tr}, x_{nm}^{j}, c_{ij}^{car}, y_{nml'l}^{j}, c_{ij}^{pub}, y_{nm}^{k}, c_{jk}$.

4. Simulating transport infrastructure expansion and economic growth

The principle objective of the simulating exercise is to assess the impacts of transport infrastructure expansion on the equilibrium levels of employment, production, consumption and the allocation of households in the region. The section starts with the description of various components of the simulated system.

4.1. Input data

The spatial structure of simulated regional economic system consists of 10 locations (nodes) and transport links connecting them. The first 5 locations correspond to the residential locations, while the last 5 to the locations of production activities. For simplicity there are not considered any transit nodes in the simulation exercise. At each production location there may operate three types of sectors: consumer goods sector (*s = 1*), high-technology sector (*s = 2*) and service sector (*s = 3*), each producing a particular type of good. Transport infrastructure of the region consists of car network and public transport network, where freight transport is supposed to use the same network as car.

The present structure of car/freight network of the region is represented at Figure 1, where thick lines correspond to the links served by monopolistic freight transport mode, with the following functional form of non-competitive profit margin function $p_{nm}(fr_{nm}) = 0.2\left(fr_{nm}\right)^{0.5}$ measured in monetary units. There is made the distinction between travel time cost functions for commuting trips and for freight transportation trips, since they are measured in different units.

Travel time cost functions for commuting trips have the following functional form $c_{nm}(f_{nm}) = 0.5\left(1 + 0.6\left(\frac{f_{nm} + 0.1fr_{nm}}{5}\right)^{0.5}\right)$ for each link of the network and are measured in hours. According to this function, 10 percent of freight transportation is performed at the same time as the residence-job trips of households and influence their commuting time.

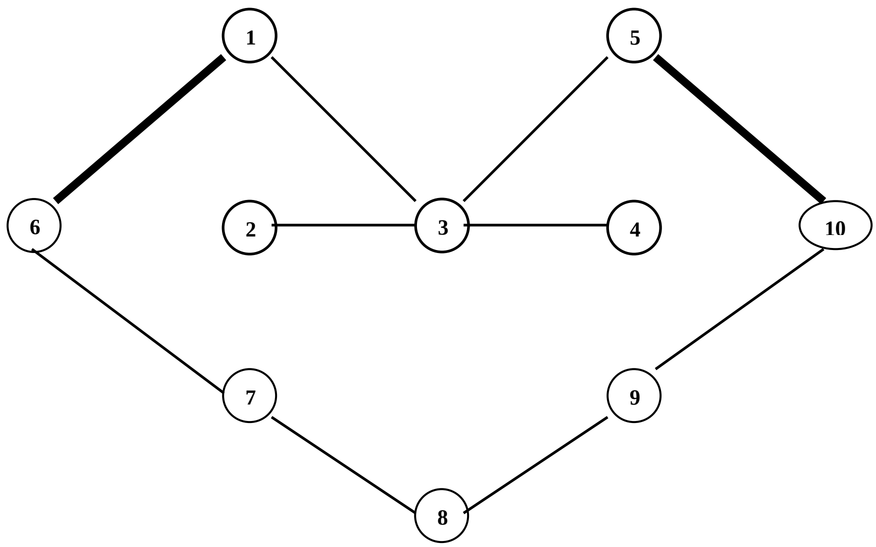

Figure 1. The present structure of car/freight network of the region

Travel time cost functions for freight transportation trips have the following functional form $c^{fr}_{nm}(fr_{nm}) = 0.1\left(1 + 0.6\left(\frac{fr_{nm}}{5}\right)^{0.5}\right)$ for each link of the network and are measured in monetary units.

The structure of public transport network is represented at Figure 2, where normal lines constitute public transport line number 1and thick lines constitute public transport line number 2. The public lines operate with different frequency parameters $f_1 = 40$ and $f_2 = 45$, measured in passengers per hour, while in-vehicle time costs are supposed to be the same for all link of the network and are equal 0.3 hours.

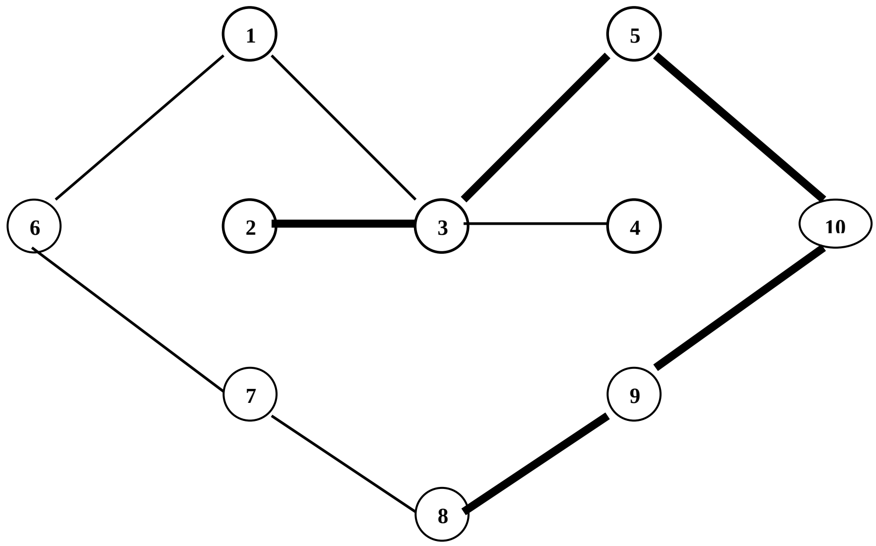

Figure 2. The present structure of public transport network of the region

Parameters of the production functions for sectors and transport agents used in simulations are represented in the Table 1. All parameters used in simulations are just guesses about the structure of production and should not be taken literally.

Table 1. Parameters of the production functions for sectors and transport agents

	s = 1	*s = 2*	*s = 3*
θ_s	13	10	15
α_s	0.4	0.4	0.4
β_s	0.2	0.3	0.2
γ_s	0.4	0.3	0.4
σ_s	0.6	0.6	0.6
σ_s^c	0.4	0.4	0.4
a_{s1}	0.4	0.4	0.2
a_{s2}	0.4	0.4	0.4
a_{s3}	0.2	0.2	0.4

	s = 1	*s = 2*	*s = 3*
θ_s^{ta}	5	6	4
v_s	0.05	0.05	0.05
σ_s^{ta}	10	10	10
a_{6s}^{ta}	0.1	0.3	0.2
a_{7s}^{ta}	0.2	0.2	0.1
a_{8s}^{ta}	0.3	0.1	0.2
a_{9s}^{ta}	0.3	0.1	0.3
a_{10s}^{ta}	0.1	0.3	0.2

Production sectors at the locations 6 and 10 are supposed to possess some market power, which is represented by their non-competitive profit margin functions having the following form $\varepsilon_{js}(y_{js}^{pr}) = 0.2\sqrt{y_{js}^{pr}}$. Sectors at these locations receive production profits that are distributed to households in the region.

Parameters of the production function for transport sector are $\theta_{tr} = 0.5$, $\alpha_{tr} = 0.3$, $\beta_{tr} = 0.3$, $\gamma_{tr} = 0.4$, $\sigma_{tr} = 0.7$, $\sigma_{tr}^{c} = 0.5$ and $a_1^{tr} = 0.3$, $a_2^{tr} = 0.4$, $a_3^{tr} = 0.3$.

It is assumed that total population of the region is $P = 50$ persons, where each of them is endowed with $h = 16$ hours per day. The endowment of time is distributed between work, commuting and leisure. Total income of a person consists of his wage, capital rent, housing rent and production profits, that are equally distributed to the population, with the total capital endowment in the region being $\overline{K} = 10$ and the total endowments of housing being $\overline{R}_1 = 5$, $\overline{R}_2 = 4$, $\overline{R}_3 = 3$, $\overline{R}_4 = 6$ and $\overline{R}_5 = 5$.

It is supposed that all persons have the same preferences, which are represented by utility function with the following parameters: $\alpha_u = 0.7$, $\sigma_u = 0.5$, $\sigma_u^c = 0.3$ and $a_1^u = 0.1$, $a_2^u = 0.5$, $a_3^u = 0.4$.

4.2. Simulation results

Using the above input data there have been performed simulation exercises for the following cases:

Case 1: (the base case) there are no changes in infrastructure

Case 2: the car/freight transport network is improved according to Figure 3

Case 3: the public transport network is improved according to Figure 4

Case 4: both car/freight transport network and public transport network are improved according to Figure 3 and Figure 4 respectively.

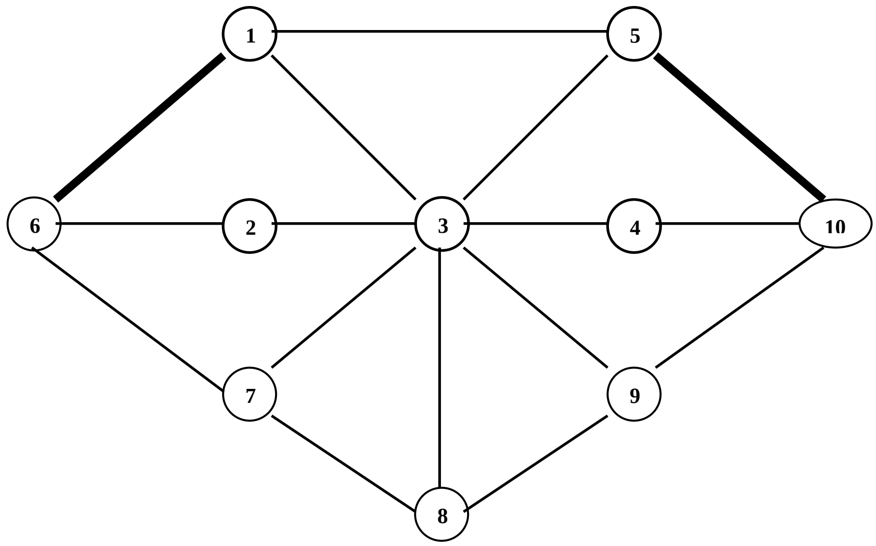

Figure 3. The improved structure of car/freight transport network

As in most cases the results of simulation exercises heavily depend upon the adopted parameters of the production and utility functions as well as on the initial characteristics of the region, but they still may give some insight into the nature of the problem and illustrate the possibilities of using the genetic SCGE model for a future empirical analysis.

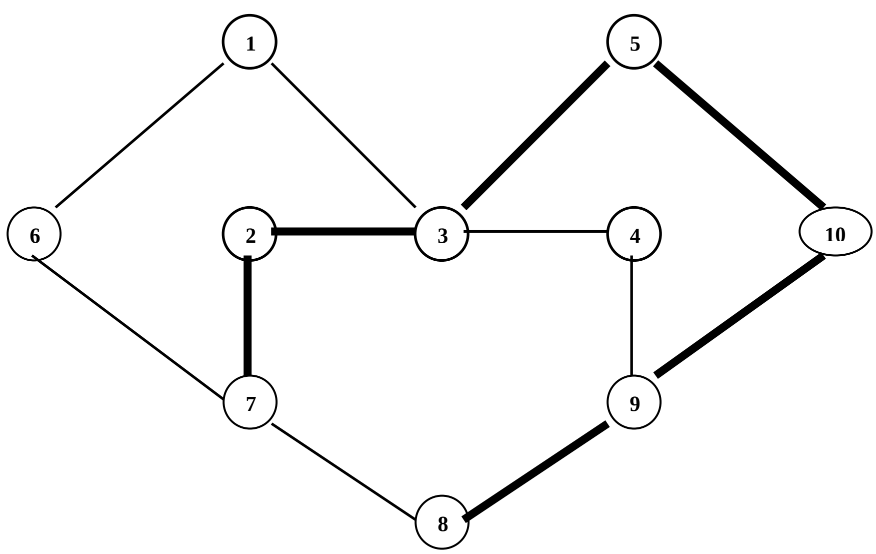

Figure 4. The improved structure of public transport network

The base case is the starting point of analysis and is used as the reference case. It allows for deriving changes in consumption, production and allocation of population in the region that are due to the expansion of transport infrastructure. Table 2 illustrates how production of the sectors is allocated in space for the base case. Each production location specializes in producing mostly one type of goods, which is explained by agglomeration effects in the region.

Table 2. Production of the sectors according to their locations for the base case in monetary units

	Sector 1	Sector 2	Sector 3
Location 6	0.01	9.08	1.65
Location 7	5.57	15.59	0.01
Location 8	50.38	0	1.91
Location 9	24.67	0	51.21
Location 10	0.01	9.15	1.6

Table 3. Consumption of goods according to the residential locations for the base case in monetary units

	Good 1	Good 2	Good 3
Location 1	35.88	11.4	17.05
Location 2	34.21	10.87	16.25
Location 3	33.05	10.5	15.7
Location 4	36.32	11.54	17.25
Location 5	35.88	11.4	17.05

Table 3 demonstrates that the consumed amounts of same good do not differ much between locations, which is explained by almost uniform distribution of the population between residential locations at the base case (Table 4). Consumption of different goods within the same location differs according to the household preferences. As demonstrated at Table 4 improvements of transport infrastructure do not have significant influence on the distribution of population between residential locations. One may conclude that the choice of residential location is mostly related to the availability of housing and not upon the structure of transport network.

Table 4. Distribution of population between the residential locations for Cases 1- 4

	Case 1	Case 2	Case 3	Case 4
Location 1	20.73 %	20.67 %	20.66 %	20.60 %
Location 2	19.17 %	19.20 %	19.24 %	19.28 %
Location 3	17.75 %	17.79 %	17.69 %	17.73 %
Location 4	21.64 %	21.67 %	21.74 %	21.79 %
Location 5	20.73 %	20.67 %	20.66 %	20.60 %

The distribution of population between locations of production activities represented at Table 5 is also nearly uniform and is not influenced significantly by changes in transport infrastructure of the region (Table 5). The choice of job location is closely related to the demand for labor at a location but not to the structure of transport network.

Table 5. Distribution of population between the locations of production activities for Cases 1- 4

	Case 1	Case 2	Case 3	Case 4
Location 6	19.38 %	19.32 %	19.35 %	19.29 %
Location 7	19.65 %	19.68 %	19.63 %	19.67 %
Location 8	20.45 %	20.56 %	20.47 %	20.58 %
Location 9	21.15 %	21.12 %	21.19 %	21.16 %
Location 10	19.38 %	19.32 %	19.35 %	19.29 %

Let us now investigate how the changes in transport infrastructure influence the total levels of production and consumption inside the region and their geographical distribution between locations. Table 6 represents total production levels of the sectors as depending upon the structure of transport network. Production of all the sectors positively depends upon infrastructure improvements, with the highest production levels corresponding to Case 4.

Table 6. Total production levels of the sectors in base case prices for Cases 1 – 4

	Case 1	Case 2	Case 3	Case 4
Sector 1	80.64	80.89	80.66	80.92
Sector 2	33.82	34.39	33.83	33.83
Sector 3	56.38	56.92	56.41	56.41

Total consumption levels of the goods also positively depend upon infrastructure improvements, with the highest ones for Case 4 as represented at Table 7.

Table 7. Total consumption levels of the goods in base case prices for Cases 1 – 4

	Case 1	Case 2	Case 3	Case 4
Good 1	175.34	175.67	175.38	175.73
Good 2	55.71	55.64	55.71	55.64
Good 3	83.3	84.2	83.33	84.24

Tables 8 – 10 and Tables 11 – 13 represent changes in geographical distribution of production and consumption respectively relatively to the base case situation for different levels of transport infrastructure development. They demonstrate that although the total levels of production and consumption just slightly influenced by infrastructure improvements their spatial distribution is changed significantly, with the most effect on the locations that were least accessible in the base case situation i.e. locations of production activities number 8 and 9 as well as residential locations number 2 and 4.

Tables 8 – 10 Changes in geographical distribution of production inside the region relatively to the base case situation for Cases 2 – 4

Table 8. Changes in geographical distribution of production inside the region relatively to the base case situation for Case 2.

	Sector 1	Sector 2	Sector 3
Location 6	0 %	-5 %	-10.3 %
Location 7	1.4 %	9.7 %	0 %
Location 8	4.3 %	-	8.9 %
Location 9	-8.1 %	-	1.3 %
Location 10	0 %	-5.4 %	-7.5 %

Table 9. Changes in geographical distribution of production inside the region relatively to the base case situation for Case 3

	Sector 1	Sector 2	Sector 3
Location 6	0 %	0 %	0 %
Location 7	-0.4 %	0.1 %	0 %
Location 8	0 %	-	0 %
Location 9	0.2 %	-	0.1 %
Location 10	0 %	0 %	0 %

Table 10. Changes in geographical distribution of production inside the region relatively to the base case situation for Case 4

	Sector 1	Sector 2	Sector 3
Location 6	0 %	-5 %	-10.3 %
Location 7	1.1 %	9.7 %	0 %
Location 8	4.3 %	-	8.9 %
Location 9	-7.9 %	-	1.3 %
Location 10	0 %	-5.4 %	-7.5 %

Tables 11 – 13 Changes in geographical distribution of consumption inside the region relatively to the base case situation for Cases 2 – 4.

Table 11. Changes in geographical distribution of consumption inside the region relatively to the base case situation for Case 2

	Good 1	Good 2	Good 3
Location 1	-0.1 %	-0.4 %	0.7 %
Location 2	0.4 %	0.0 %	1.3 %
Location 3	0.4 %	0.1 %	1.3 %
Location 4	0.5 %	0.2 %	1.4 %
Location 5	-0.1 %	-0.4 %	0.7 %

Table 12. Changes in geographical distribution of consumption inside the region relatively to the base case situation for Case 3

	Good 1	Good 2	Good 3
Location 1	-0.3 %	-0.4 %	-0.4 %
Location 2	0.5 %	0.5 %	0.5 %
Location 3	-0.3 %	-0.4 %	-0.3 %
Location 4	0.6 %	0.6 %	0.7 %
Location 5	-0.3 %	-0.4 %	-0.4 %

Table 13. Changes in geographical distribution of consumption inside the region relatively to the base case situation for Case 4

	Good 1	Good 2	Good 3
Location 1	-0.5 %	-0.9 %	0.4 %
Location 2	0.9 %	0.6 %	1.8 %
Location 3	0 %	-0.3 %	1 %
Location 4	1.2 %	0.9 %	2.1 %
Location 5	-0.5 %	-0.9 %	0.4 %

Let us also check if infrastructure improvements have any influence on the non-competitive profits of sectors at the locations 6 and 10. Table 14 represents the levels of total non-competitive profits as depending upon the structure of transport network. It appears that they are slightly reduced as the result of infrastructure changes.

Table 14. Levels of total non-competitive profits at the locations 6 and 10 for Cases 1 – 4

	Case 1	Case 2	Case 3	Case 4
Location 6	5.89	5.43	5.89	5.43
Location 10	5.94	5.46	5.93	5.45

Let us now consider how infrastructure improvements influence performance of the network itself. Amounts of transported goods have increased as demonstrated at Table 15, which is due to lower time travel costs and improved accessibility of locations.

Table 15. Total values of transported goods in prices of the base case for Case 1 – 4

Case 1	170.79
Case 2	172.26
Case 3	170.83
Case 4	172.27

The division of commuting trips between car and public transport is significantly influenced by transport infrastructure improvements as demonstrated at Table 16.

Table 16. Division of commuting trips between car and public transport for Cases 1 – 4

Using	Case 1	Case 2	Case 3	Case 4
car	54 %	67 %	40 %	56 %
pub transp	46 %	33 %	60 %	44 %

Improvements of a particular type of network (for car or public transport) decreases time travel costs on it and leads to greater share of commuting trips performed using this type of network.

In order to measure accessibility of the region as a whole and of each residential location in particular the following types of accessibility measures are used (Pooler, 1995):

$$A_i = \sum_j P \cdot \Psi_{ij} \exp\left(-\frac{c_{ij}^{car} + c_{ij}^{col}}{2} \right) \quad \text{for } i = 1,..,5$$

are the accessibility measures of all residential locations and

$$A = \frac{1}{5} \sum_i A_i$$

is accessibility measure of the region as a whole.

The measures calculated according to these formulas are represented at Table 17 and demonstrate that not all locations gain in accessibility from infrastructure improvements. For example the location 4 loose in accessibility in Case 3, when only public transport network is extended, which may be due to increased demand for public transport and hence higher waiting times between particular residence-job locations. Accessibility of the region as a whole for Cases 1 – 4 is represented at Table 18 and demonstrates that infrastructure improvements do have significant effect upon the accessibility of region, with the highest one corresponding to Case 4, when both car transport and public transport networks are extended.

Table 17. Accessibility measures of the residential locations for Cases 1 – 4

	Case 1	Case 2	Case 3	Case 4
Location 1	3763.85	3782.94	3767.02	3786.42
Location 2	3834.44	3849.39	3830.75	3845.38
Location 3	3896.62	3911.85	3899.48	3915.01
Location 4	3726.05	3739.47	3720.61	3733.48
Location 5	3763.84	3782.93	3767	3786.41

Table 18. Accessibility of the region as a whole for Cases 1 – 4

Case 1	3796.96
Case 2	3813.32
Case 3	3796.97
Case 4	3813.34

5. Concluding remarks

The present paper has illustrated the possibility of developing the generic SCGE model incorporating location decisions of households and firms, equilibrium on housing market, market imperfections and real transport network equilibrium. The developed model captures the effects of infrastructure improvements at both micro-economic level, regional economic level and the level of real transport network performance, thus allowing researches to perform complete empirical analysis of the role, which transport infrastructure and its expansion plays in economic development of a region.

The generic SCGE model allows one to analyze the welfare benefits of a particular new infrastructure link in the complete manner using data available in most of the countries. Solution time for such a model is relatively low, which gives a transport ministry the possibility to analyze significant number of separate infrastructure investment projects and combinations of them and hence to choose the optimal allocation of infrastructure investments, given the specific economic structure and transport network of a region or a country.

The model also gives governments the possibility to forecast future transport flows, given the forecasts of future production growth rates in a region or a country. Hence, it represents a useful tool for understanding the magnitude and location of future needs in transport infrastructure and may help governments to stimulate regional economies using adequate transport infrastructure provision or at least make it compatible with future economic growth.

The simulation exercises performed in the paper are rather simple ones and their aim is to prove functionality of the model. They demonstrate the positive relationship between growth of production and consumption in the region and infrastructure improvements. Although expansion of production, due to infrastructure development is rather small, one may expect that the absence of such expansion in case of increase in population and in future production may prevent normal economic development of a region. Simulations with the model also demonstrate that non-competitive profits of the sectors are slightly reduced as the result of infrastructure improvements. Due to changes in price levels at locations and changes in location decisions of households in the region, consumption and production of goods are relocated.

One should remember that figures used for simulations are hypothetical ones and with real data, slight changes in production, consumption and non-competitive profits may be rather significant in monetary value and demonstrate that infrastructure improvements are highly beneficial for economy of a region. Simulation exercises demonstrate wide possibilities of the developed model and give guidelines for future empirical research, which is possible to perform with it.

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Appendices

TØI report
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PINGO
A model for prediction of regional- and interregional freight transport

Version 1

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Contents

Preface

In spring 2001 the Ministry of Transport and Communications invited a selection of research institutes to send project proposals to program for overall transport research (POT). The first part of our project proposal about implementation and calibration of a SCGE model for Prediction of regional and INterreGiOnal freight transport (PINGO) got financial support from POT.

This report describes the work we have accomplished as part of the project. The main project workers were msc env dev econ Olga Ivanova, cand oecon Viggo Jean-Hansen and dr scient Arild Vold.

Arild Vold has been the project leader and worked out the broad structure of the model. Olga Ivanova has refined and implemented the model and Viggo Jean-Hansen has obtained the necessary data. As part of the work to decide on the final model structure and the necessary data, there have been numerous good and fruitful discussions between the three co-workers.

We want to thank Knut Sandberg Eriksen, Harald Minken and Farideh Ramjerdi for comments on draft versions of the report. We would also like to thank Kjell Werner Johansen who has been responsible for quality assurance, and Laila Aastorp Andersen who has provided secretarial assistance.

Oslo, April 2002
Institute of Transport Economics

Knut Østmoe	*Kjell Werner Johansen*
Managing director	Head of Department

1 Introduction

Freight transport is crucial for the economy since production and consumption of commodities is located in different places. Reduced monetary and time costs of transportation enable firms to sell their products more cheaply, which in turn stimulates greater demand, gives rise to economic growth, but can of course affect emissions and environmental degradation.

Forecasts for how the economy and the environment is affected by demographic changes, new transport taxes, infrastructure investments within the transport sector, and economic growth are needed to assist the Norwegian government for long-term planning of transport infrastructure provision, regional development, environmental policy and taxes.

Canada, USA and Italy already have models for forecasting transport demands between and within counties and use them successfully in regional planning. Most of the models are implemented in the framework of Spatial Computable General Equilibrium (SCGE) modelling. The theoretical basis for such models is a complete Arrow-Debreu economy under perfect competition, where transport is considered as an input factor into production of goods and services, representing a cost to individual businesses. Some regional SCGE models are based on the assumption that transport services are imported from some external supplier. Others incorporate the transport sector into the economy and represent its production technology using CES-functions.

In Norway we have the regional economic models REGARD (Johansen, 1997) and REGION-2 (Sørensen and Toresen, 1990). Both models forecast economic development in Norwegian counties, which includes inputs to the production sectors, production and consumption. Total transport of commodities out of and into each of the counties are assessed, but not the transported amount of commodities between pairs of counties. REGION-2 uses a fixed relationship between inputs in the production sectors, which means that the share of different inputs in production of commodities is not sensitive to price changes. Hence, REGION-2 does not contain any producer behaviour (Sørensen and Toresen, 1990, s.10).

The real network model for freight transport within Norway and between Norway and other countries (NEMO, Vold et al., 2002) assess OD matrices for transport costs and OD matrices for transport volumes between pairs of counties in a base year (1999). NEMO assigns the volumes in the OD matrices to the links in the transport network in a way that minimises the total costs of transport (System Optimum).

Even if NEMO alone cannot forecast future freight volumes with the different transport modes, it gives a good starting point for building a regional economic model that makes forecasts also for transport between pairs of counties in Norway. Earlier approaches to project transport volumes from NEMO to a future year includes application of the CGE model GODMOD (Jensen and Eriksen, 1997) and REGARD (Madslien, Jule and Jean-Hansen, 1998). The use of GODMOD was TOI's first attempt to use CGE models for this purpose. GODMOD represents the economy in a theoretically plausible way but includes no spatial description, whereas with REGARD there is the opposite.

To take a step further, the Ministry of Transport and Communication therefore commissioned the construction of a SCGE model of the Norwegian economy emphasising freight transport and forecasts of growth rates for national freight movement within counties and between pairs of counties in Norway and between counties in Norway and other countries. The task was entrusted to the Institute of Transport Economics (TØI). This report describes development and implementation of the first version of this SCGE model, which is named PINGO.

PINGO is a slightly modified version of the SCGE model developed by Bröcker (1998). The major difference is that the Bröcker's model does not include an explicit transport sector, whereas PINGO includes explicit representation of a transport sector as well as import and export activities. Bröcker assumes that a certain percentage of the transported commodity itself is used during transportation (iceberg effect), where the amount of the commodity used during transportation, depends upon its type and travel distance.

Input to PINGO includes OD matrices for freight transport within and between counties in a base year and freight transport costs. The freight transport costs can be obtained from NEMO. Calibration of PINGO is usually based on freight transport costs in a base year, whereas subsequent runs can be based on freight transport costs where new fuel taxes, infrastructure investments etc., can be included (Figure 1.1). PINGO predicts the long-term effects of the new transport costs on freight transport within and between counties for each of the ten commodity groups that are represented in NEMO, while accounting for changed population in the counties and economic development (i.e., new taxes, new production technology etc.). Growth rates for freight transport within and between counties from PINGO can subsequently be used to update the OD-matrices, whereat NEMO can be used to calculate corresponding figures for tonne kilometres, environmental costs etc. at a different levels of aggregation.

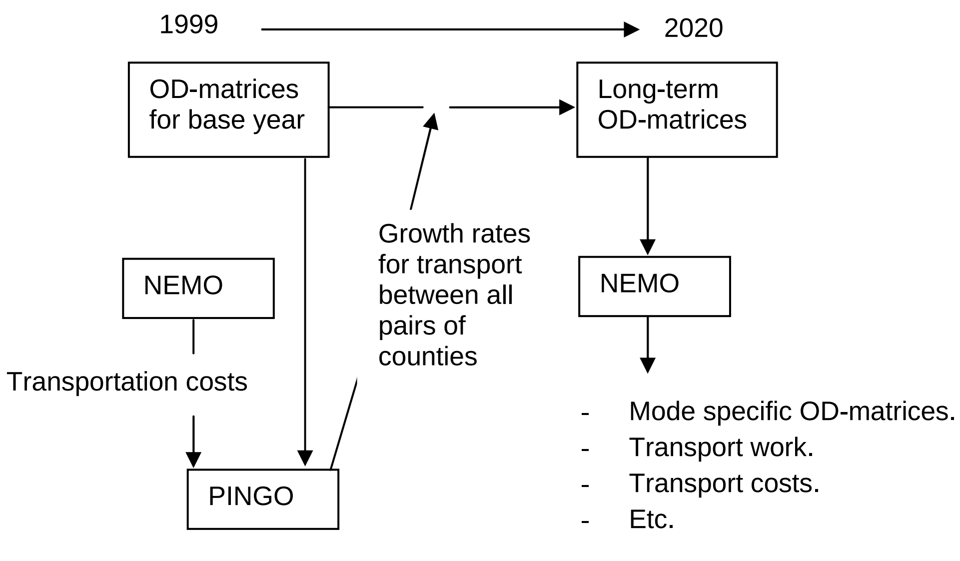

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Figure 1.1. A schematic view of the interplay between NEMO and PINGO.

The main advantage of PINGO compared to earlier approaches to this kind of modelling is the structure of freight delivery and receiving between counties.

The first version of PINGO is described in chapter 2 and the collection and treatment of data that are used as model input and for model estimation is described in chapter 3. Results from four test cases are presented in chapter 4, and a procedure for how to apply the model to make forecasts is described in chapter 5. Chapter 6 contains future perspectives for the model development and the appendixes include detailed information about CES functions and a simple test case.

2 Description of PINGO

Although endowments of the consumers are the only exogenous variables that need to be fixed in the model, there is the option to set almost all variables in PINGO exogenously. The variables to be made exogenous are determined by the user according to the aims of his analysis. Some examples of possible exogenous variables and their use in the analysis performed with the model are given in the test cases presented in chapter 4.

2.1 Structure of the model

In order to determine how to subdivide Norway in regions that are suitable for PINGO we considered the advantages and disadvantages of a detailed subdivision. With a detailed subdivision, we are potentially more able to assess variations at local level. The need for data and computational resources increases with increasing number of regions. National Accounts Statistics by County is available for the 19 Norwegian counties, but it is much more difficult to obtain data for smaller regions.

We decided to use the 19 Norwegian counties as regions and a single region to represent all foreign countries in PINGO (Figure 2.1). Neither NEMO nor PINGO represent Svalbard and there is no explicit representation of the crude oil production on the Continental shelf but the income from this activity is implicitly represented in PINGO as transfer of money from the government to the households in the counties[1].

PINGO includes 10 *commodity groups* and 2 types of *services*. Each county shelters 9 different *production sectors* that produces the 10 commodity groups, one *service sector* that produces the 2 services and one *investment sector* that produces physical capital for the county where it is located, where physical capital is bounded to county where it is produced.

There is final demand by 19 representative *households* (one household per county). On the national level there is a *national transport sectors*, an *import sector*, an *export sector* and a *government sector* that balances the economy.

There are 10×19 *commodity agents* (one agent per commodity and county) and 2×19 *service agents* (one agent per service and county). The commodity agents can be interpreted as the wholesalers or retailers who use output of a commodity group from all counties and other countries and transport services, carried out by the national transportation sector, to produce a *pooled commodity* corresponding to one of the commodity group. Only the pooled commodity can be consumed or used as an input factor in the county where the commodity agent is located. The service agents trade repair and other services.

[1] In most of the counties there are large positive figures for the households' operating surplus commodities, which may be interpreted as transfers from the government to the households.

There is no distinction between different types of labour in PINGO, and the endowment of labour in each county is fixed (i.e., it is assumed that labour is a limited resource, there is no unemployment, and labour is immobile between the counties).

There is no explicit representation of profits/losses, monetary investments, taxes/subsidies from the government and many other things in the sectors in PINGO. Due to the complexity of such realistic modelling and certain data requirements we have chosen to represent all factors not taken explicitly into account by the *operating surplus commodity* that is used to balance the sectors accounts. The operating surplus commodity is county specific and is either produced or consumed by the sectors. Operating surplus is interpreted as input to production when the producers receive profit and as output when they face losses.

A later version of PINGO will hopefully represent more components in an explicit way, however, and less components as part of the operating surplus commodity.

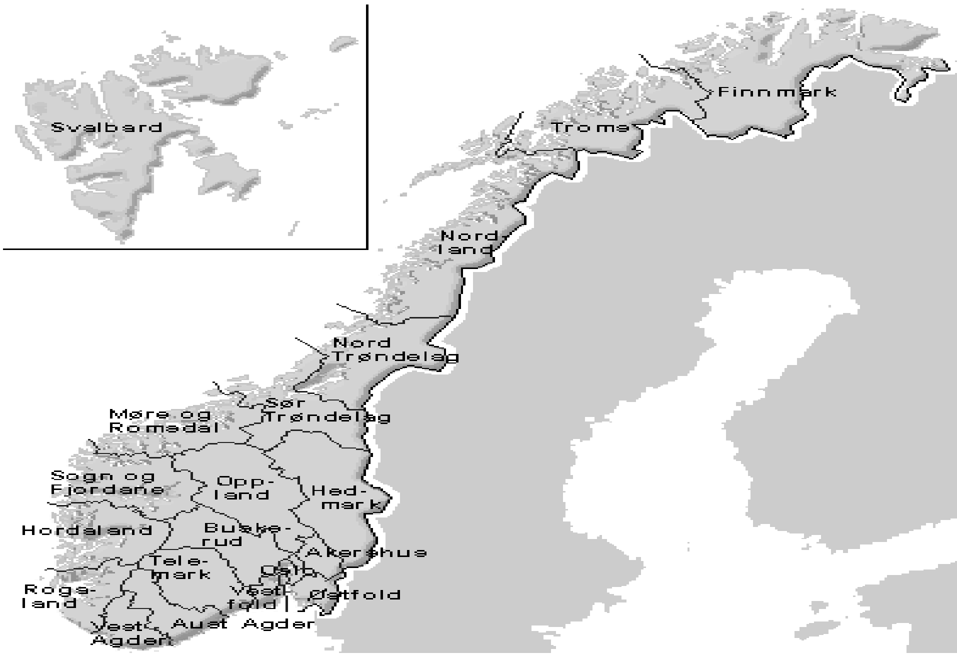

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Figure 2.1. Counties in Norway: 01 Østfold, 02 Akershus, 03 Oslo, 04 Hedmark, 05 Oppland, 06 Buskerud, 07 Vestfold, 08 Telemark, 09 Aust-Agder, 10 Vest-Agder, 11 Rogaland, 12 Hordaland, 14 Sogn and Fjordane, 15 Møre and Romsdal, 16 Sør-Trøndelag, 17 Nord-Trøndelag, 18 Nordland, 19 Troms, 20 Finnmark

2.2 The Social Accounting Matrix

We use a Social Accounting Matrix (SAM) to represents an equilibrium situation where all the economic agents[2] and goods in PINGO are represented. The columns of the matrix

[2] An economic agent can be a production sector, investment sector, service sector, commodity agent, service agent or a representative household, or the national transport sector, import sector, export sector and the government.

represent the economic agents accounts while its rows represent markets for goods and factors of production. Transport of each commodity within each county and between all pairs of counties is represented on the off-diagonal sub matrices of the SAM. Positive elements in the columns are outputs of goods or endowments of factors of production, while negative are inputs or demands. Economic equilibrium implies that all economic agents and markets are in balance, i.e., that rows and columns have zero sums, respectively.

Although the SAM matrix used in PINGO represents the Norwegian economy as divided into 19 counties plus one county that corresponds to all other countries, we used a SAM matrix for only two counties with synthetic data but with the same structure that is used in the full-scale version of PINGO to verify a small-scale prototypical version of the PINGO model (Table 2.2).

There are two production sectors, one transport sector, and one sector for private consumption. There are two commodity groups, commodity agents, and a national transport sector. A national authority may transfer money in terms of subsidies and taxes, which is part of the balancing factors in the economy. The small-scale version was verified, but we do not present any of the results in this report.

Table 2.2. A stylistic Social Accounting Matrix (SAM)

		Region 1						Region 2									
		Sector 1	Sector 2	Tr agent 1	Tr agent 2	Household	Inv sector	Sector 1	Sector 2	Tr agent 1	Tr agent 2	Household	Inv sector	Transp sector	Import	Export	Government
Region 1	good 1	1630	100	-120	0	0	0	0	0	-500	0	0	0	0	0	-780	0
	good 2	330	2100	0	-980	0	0	0	0	0	-800	0	0	0	0	-620	0
	pool good 1	-20	-200	1647	0	-1077	-350	0	0	0	0	0	0	0	0	0	0
	pool good 2	-330	-35	0	2129	-1247	-490	0	0	0	0	0	0	0	0	0	0
	labor.reg2	-550	-580	0	0	2051	0	0	0	0	0	0	0	-31	0	0	0
	phys capital	-870	-1291	0	0	0	2181	0	0	0	0	0	0	-20	0	0	0
	oper surplus	-130	-94	0	0	270	-206	0	0	0	0	0	0	0	0	0	130
Region 2	good 1	0	0	-850	0	0	0	2500	230	-1200	0	0	0	0	0	-680	0
	good 2	0	0	0	-720	0	0	120	1800	0	-850	0	0	0	0	-350	0
	pool good 1	0	0	0	0	0	0	-80	-630	2354	0	-1204	-440	0	0	0	0
	pool good 2	0	0	0	0	0	0	-780	-60	0	1984	-844	-300	0	0	0	0
	labor.reg2	0	0	0	0	0	0	-320	-590	0	0	2115	0	-25	0	0	0
	phys capital	0	0	0	0	0	0	-1052	-680	0	0	0	1744	-12	0	0	0
	oper surplus	0	0	0	0	0	0	-88	-70	0	0	-67	35	0	0	0	190
	tr.reg1-reg2	0	0	-8	-7	0	0	0	0	-4	-6	0	0	25	0	0	0
	tr.abroad-reg1	0	0	-9	-12	0	-15	0	0	0	0	0	0	36	0	0	0
	tr.abroad-reg2	0	0	0	0	0	0	0	0	-10	-8	0	-9	27	0	0	0
	good1.imp	0	0	-360	0	0	0	0	0	-640	0	0	0	0	1000	0	0
	good2.imp	0	0	0	-410	0	0	0	0	0	-320	0	0	0	730	0	0
	capital.imp	0	0	0	0	0	-230	0	0	0	0	0	-150	0	380	0	0
	trade bal corr	0	0	0	0	0	0	0	0	0	0	0	0	0	-2110	2430	-320

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2.2.1 Balance for economic agents

The production sectors in the counties choose inputs and outputs according to cost minimising and profit maximising behaviour, respectively, taking into account the market prices (see Appendix 1). Balanced production of the ten commodities, ten pool commodities, two services, two pooled services, the physical capital and the operating surplus commodity by the economic agent *s* in a county *r* in an equilibrium situation can be represented by the following production possibilities set

$$f_{sr}(X_{s1r},...,X_{s26r,}H_{s1r},...,H_{s20r},H_{s26r}H_{s27r},T_{s1r},...,T_{s170r})=0\,,$$

where X_{sir}, i = 1,…26, denotes output, H_{sir}, i = 1,…,26 denotes inputs of all produced goods plus inputs of county specific labour provided by households H_{s27r} and T_{sjr} , j = 1,…,170 denotes inputs of the various transport services. To achieve this balance, the amount of operating surplus commodity produced/consumed is calculated in such a way that the accounts for each sector balance.

Households in the counties perform consumption activities by selling their labor endowments to the production sectors and using the received income on the consumption of pool commodities. To achieve the balance of the activities for the households the operating surplus commodity is used.

Except for the economic agents on the county level there are also a number of production sectors at the national level such as the transport sector, the export and import sectors as well as the government sector. The balance of the activities for these economic agents is achieved by adjusting the produced/consumed amount of the trade balance commodity.

2.2.2 Balance for economic markets

Positive figures in the SAM correspond to inflow of goods and factors of production in the economy while negative to their outflow. According to the principle of the sign the whole model may be divided into a part for *supplies and outputs* and a part for *demands and inputs*. The two parts are supplementing in the sense that the supplies and outputs provides inflow of commodities, services and factors into the economy, whereas the demands and inputs represents the use of all available commodities, services and factors of production.

The sum of *supplies and outputs* of good *i* in county *r* is

$$Q_{ir} = \sum_{s} X_{sir} + \sum_{r'} ZM_{ir'r} + I_{ir} + \sum_{s} GX_{sir}\ ,$$

where $ZM_{ir'r}$ denotes delivery of goods from county *r'* to county *r*, I_{ir} denote import to county *r*, where imported goods is used in the county where it is imported, and GX_{s26r} denotes the operating surplus commodity if it represents supplies. Here the list of elements, which are non-zero in this equation, depends on whether the equation represents commodities, physical capital or services (X), pooled commodities or pooled services ($ZM + I$) or operating surplus commodities (GX).

Outputs of transport services needed to transport the total amount of commodities from county r' to *r* that is produced by the national transport sector is denoted

$$Q_{r'r} = TX_{r'r}\,.$$

The export sector buys commodities from the counties in order to export them abroad, and earn trade balance commodity in the amount *EX*. The trade balance is also possibly produced or consumed by the government sector in the amount *GB* if the value of export is less than the value of import and vice versa, respectively (i.e., operating surplus commodity in the amount *GB* is produced by the government in order to cover the trade balance deficit in case when the value of export is less than the value of import.). Thus, the output of the trade balance commodity becomes

$$Q_B = EX + \max\{0, GB\} .$$

The *demands and inputs* part of the model includes the households consumption of pooled commodities (*C*), the need for inputs (*H*) of pool commodities and pool services, labour and physical capital, delivery of goods in producer prices to other counties (*ZL*), export of goods from the counties to other countries (*A*) and demand and input of operating surplus commodities in the amounts (*G*). The demand and inputs of commodity *i* in county *r* become

$$R_{ir} = C_{ir} + \sum_s H_{isr} + \sum_{r'} ZL_{irr'} + A_{ir} + \sum_s G_{sir}$$

The list of the elements that are non-zero in this equation depends on whether the equation represents commodities, pooled commodities, services, pooled services, labour, physical capital or operating surplus commodities.

Demand for the transport services is given by

$$R_{r'r} = \sum_s H_{sr'r} ,$$

where $H_{sr'r}$ denotes input of the transportation between counties r' and *r* into the production of sector *s* in county *r*.

The demand equation for the trade balance commodity is $R_B = IH - \min\{0, GB\}$, where *IH* denotes demand of the trade balance commodity of the import sector and *GB* is the amount supplied or demanded by the government if the value of export is less than the value of import and vice versa.

Balance of the economic markets requires that $Q_{ir} - R_{ir} = 0$, $Q_{r'r} - R_{r'r} = 0$ and $Q_B - R_B = 0$, where the demands of a county *r* are supplied by deliveries from other counties and foreign countries (see Figure 2.2). This balance is obtained by adjusting the government's production/consumption of the operating surplus commodity, where main part of these adjustments is the taxes/subsidies that make up the price difference between seller and buyers market prices.

The trade balance commodity is finally used to simultaneously balance the government sector and the import and export activities, where the amount of the trade balance commodity in the government sector is interpreted as the national surplus or the national deficit depending on its sign. The amount of trade balance commodity that is finally needed to balance the government sector and the import and export activities also balances the market for the trade balance commodity, which is the consequence of a well-known property of matrices (Hardley, 1973). Thus all rows and columns of the SAM ultimately sum to zero.

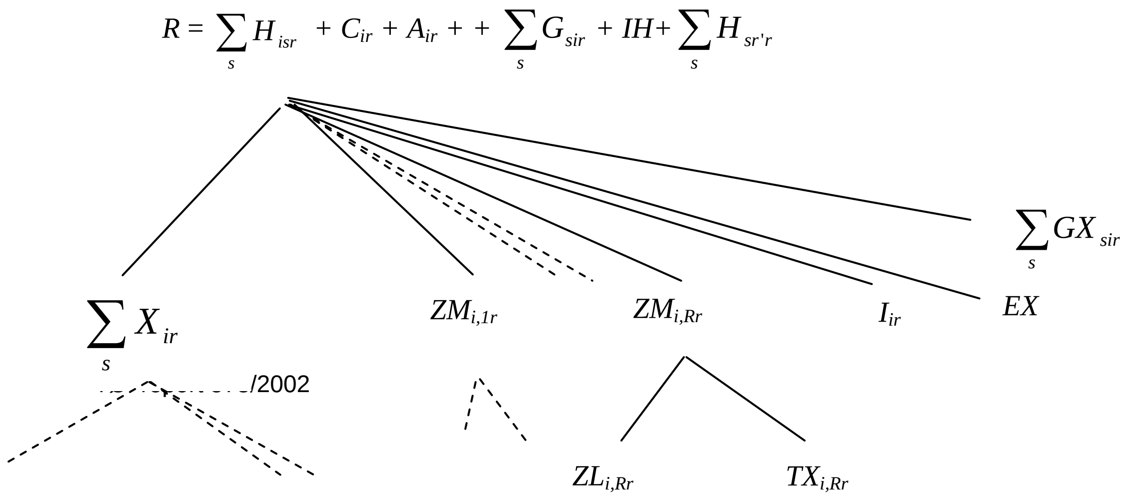

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Figure 2.2. Schematic view of the demand (*R*) of commodity *i* in county *r* and the supply (*Q*) of commodity *i* from all counties and other countries, where *R* is represented as the output at the "top" level and *Q* is represented as input at lower levels. An equilibrium situation requires that *R* - *Q* = 0.

2.3 Goods groups and economic agents in PINGO

2.3.1 Commodities and services in the model

Vold et al., (2002) choose 10 commodity groups for use in NEMO based on the requirements (1) that commodity groups can be linked to well-defined business sectors, (2) that the collection of commodities within each commodity group should have approximately the same requirements for transport quality (and thus transport costs), (3) that available data are sufficient to construct base year OD matrices for the commodity groups, and (4) that the shares of the commodity groups that are produced should vary little among the municipalities.

The commodity groups in PINGO are similar to those in NEMO, except that PINGO also includes a commodity group for physical capital (which is also a primary factor in production), whereas fish is not subdivided into fresh and frozen good in PINGO. The following groups of goods (commodities or services) are represented in PINGO:

***(01)** food, **(02)** fish, **(03)** thermo, **(04)** vehicles/machinery, **(05)** general cargo, **(06)** timber and wood ware, **(07)** coal, sand and gravel, **(08)** chemical products, **(09)** metals and ore, **(10)** bulk commodities (liquid), **(11)** reparation services, **(12)** other services, **(13)** physical capital.*

The fact that most available data sources group commodities according to business sectors, put strong constraints on how the commodity groups could be further aggregated to NEMO commodities. It is our opinion, however, that the groups are also relevant with respect to transport quality. Food, fish, thermo (food that require cooling or freezing while transported), and liquid bulk are all commodities with special requirements for transport quality. Chemical products and liquid bulk are both commodities that are classified as dangerous goods.

2.3.2 Production, service and investments

PINGO's production sectors produce different types of commodities using primary factors of production (labour and physical capital) as well as pool commodities and pooled services as inputs. The service sectors in their turn produce two types of services using the same types of inputs as the production sectors.

We have grouped and aggregated the 174 sectors that are represented in National Accounts Statistics by County (NAC) and the corresponding production of goods into a set of PINGO sectors for each county:

(01) food production, (02) fisheries, (03) timber, wood ware, paper and cardboard, (04) production of masses, (05) hardware production, (06) chemical industries, (07) production of metals and metal products, (08) bulk production, (09) high value products. There is also a sector for private and public services (10) in each county, and one (11) investment sector in each county that produces physical capital using pool commodities and county specific labour as input factors. An investment sector can only use labour from the county where it is located and produce physical capital for use in the county where it is located for maintenance of existing capital and new investments. The investment sectors themselves may use physical capital for production; hence figures for outputs of the investment sectors represent outputs of physical capital net of its intermediate consumption. Amounts of physical capital produced by each county specific investment sector is equal to the annual investments in the county, which include newly made investments as well as investments made to cover capital depreciation.

The largest output commodity from a sector is defined as the primary commodity for the sector. Other output commodities are termed secondary (Table 2.1, se also Jean-Hansen, 2001).

The primary good produced by the food production sector is the thermo commodity, whereas food and general cargo are secondary products. The fisheries produce fish as a primary commodity and thermo goods as a secondary commodity and so on. General cargo is a primary commodity in three PINGO sectors (sectors 3, 4 and 9). Food is not the primary commodity in any sector, but the secondary product in the food production sector.

Production technology for the production sectors is described by two level CES functions (Figure 2.3). The elasticity of substitution between labour and physical capital is 1, which corresponds to Cobb-Douglas technology and the elasticity of substitution between pool commodities is zero, which corresponds to Leontief technology. The elasticities of substitution between primary factors and the intermediate input goods are zero. It is further assumed that outputs from the production sectors are produced in fixed proportion, i.e., the elasticity of transformation between outputs is zero.

The operating surplus commodity is used (produced) in fixed proportion to other inputs (outputs). Hence there is a fixed rate of profit (loss) for each producer, derived from the base year situation.

Table 2.1. Production of primary and secondary commodities in the sectors represented by PINGO. Figures in brackets show the share of the total production of that is produced as secondary commodities

Sector in PINGO	Primary and secondary commodities								
1 Food production	Food (99)		Thermo		General cargo (10)				
2 Fisheries		Fish	Thermo (8)						
3 Timber, wood ware, paper and cardboard					General cargo	Timber and wood ware (99)		Chemical products (1)		
4 Production of masses					General cargo		Coal, sand and gravel (98)	Chemical products (1)	Metals and ore (2)	
5 Hardware production				Vehicles/ machinery					Metals and ore (3)	
6 Chemical industries					General cargo (2)			Chemical products	Metals and ore (1)	Bulk commodities (liquid) (1)
7 Production of metals and metal products				Vehicles/ machinery (8)			Coal, sand and gravel (1)		Metals and ore	
8 Bulk production							Coal, sand and gravel (1)			Bulk commodities (liquid)
9 High value products				Vehicles/ machinery (1)	General cargo			Chemical products (2)		
10 Private and public services										
The share of the production of the commodity as a primary commodity in one or several sectors.	0	100	91	91	87	0	0	96	94	100

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Investment sectors produce physical capital with Leontief technology and county specific pooled commodities as inputs (Figure 2.4).

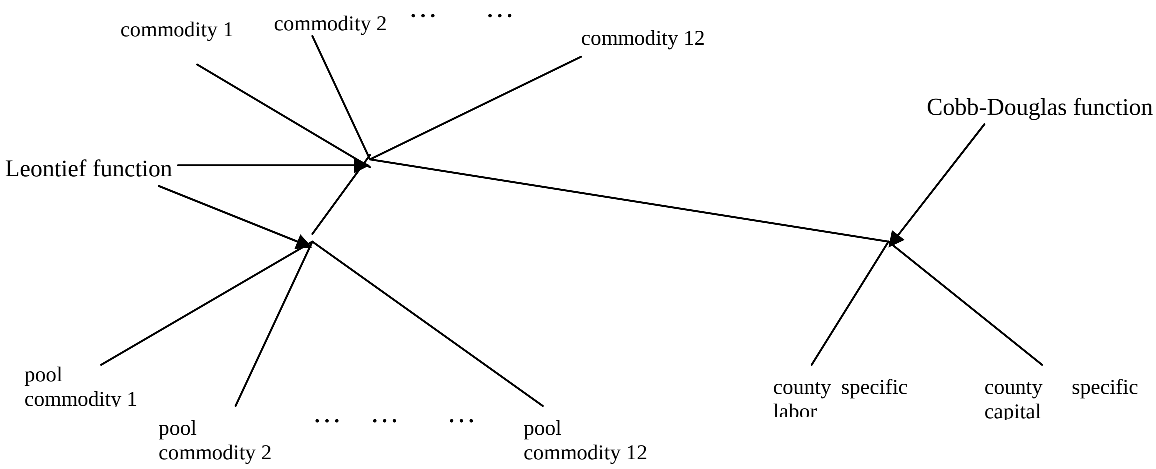

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Figure 2.3. Production tree for the production sectors.

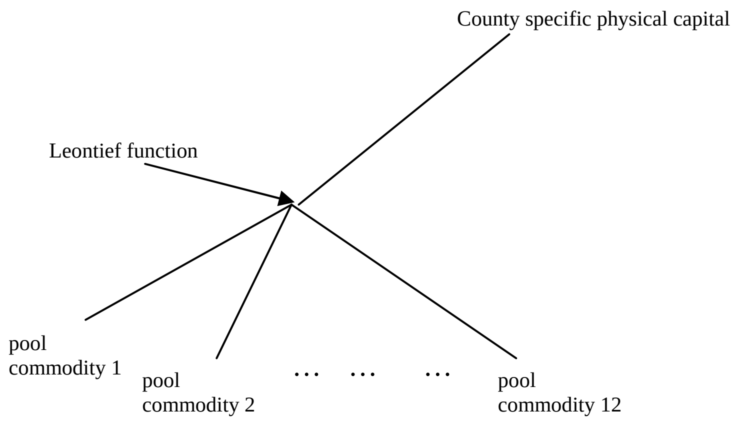

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Figure 2.4. Production tree for the investment sectors.

2.3.4 Transport services and agents

Since the transportation undertaken by the production sectors themselves is not represented as part of the National Accounts statistics, we had to make the assumptions that the costs for transport services are similar irrespective of whether they are organised by a specialised transport company or whether they are organised by the production sectors themselves. PINGO represents a national transport sector that undertakes transport of all commodities between all pairs of counties in Norway and between counties in Norway and other countries. The national transport sector is considered internal to the economy in the sense that the inputs are domestic labour from the respective counties that receives the transported goods and physical capital and pooled commodities.

A two level CES function represents the technology of the national transport sector. Input factors encompass labor from different counties and pooled commodities. The labor from different counties is merged with zero elasticity of substitution at the "bottom" level and various pooled commodities are merged likewise. Labor and pool commodities are then used in fixed proportions in order to produce transport services at the "top" level (Figure 2.5). The elasticity of transformation for the transportation sector production function is set at a large value, so that production of one transportation service may be perfectly substituted for the other.

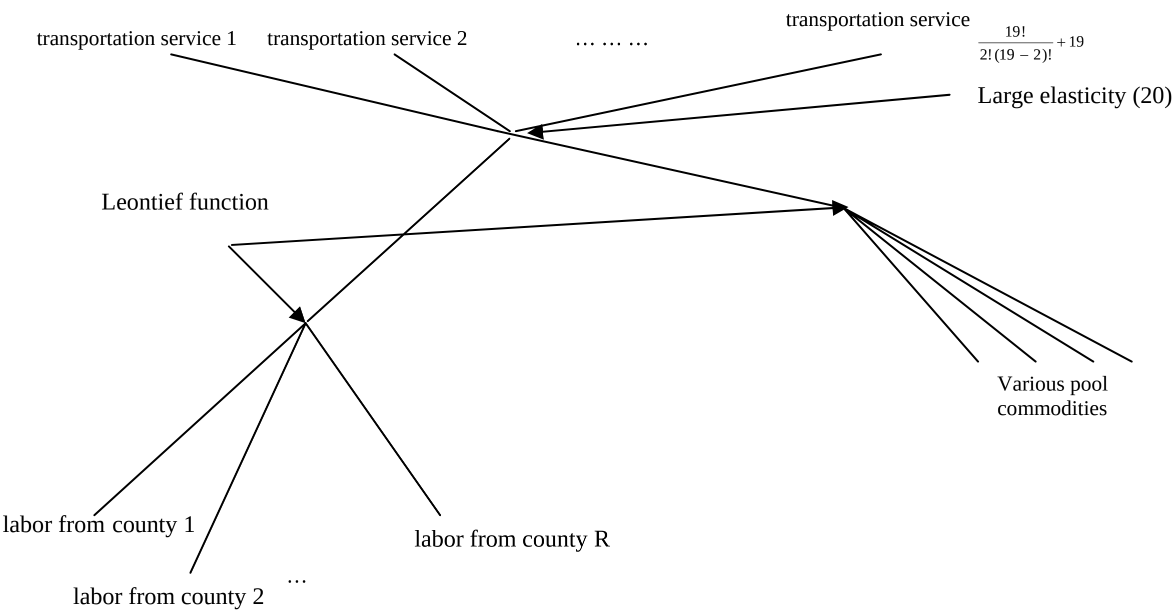

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Figure 2.5. Production tree for the transport sector.

Each of the 10 commodity groups in PINGO is associated with a commodity agent. His activity can be thought of as being separated into two parts: one part is to use transport services to transport commodities from all counties to the county where the agent is located; the other is merging the amounts arrived into the pool. The commodity agents use transport services for transport of a commodity group from one or several domestic counties and foreign countries into a pooled commodity[3] that is sold and used as input or for consumption in the county where the commodity agent is located.

The prices of pool commodities depend on the producer prices in the counties and the transportation costs. Commodity agents incur costs of transporting commodities from different counties, as well as prices of commodities from these counties. If the price of a produced commodity is reduced in a specified county, then the commodity agents tend to use more of the commodity from this county and less from other counties. The amount that is substituted depends on the relative prices as well as on the elasticity of substitution for the agents.

At the "bottom" level of the commodity agent's CES function, commodities from the counties and transport services are used in some fixed proportions according to Leontief technology. At the "top" level, the commodity agent is merging the transported commodities into a pool (Figure 2.6).

We have assumed rather large elasticity of substitution (20) between the same types of goods produced in different counties. It is our intention, however, to estimate this elasticity according to appropriate estimation methods and empirical data in future versions of PINGO.

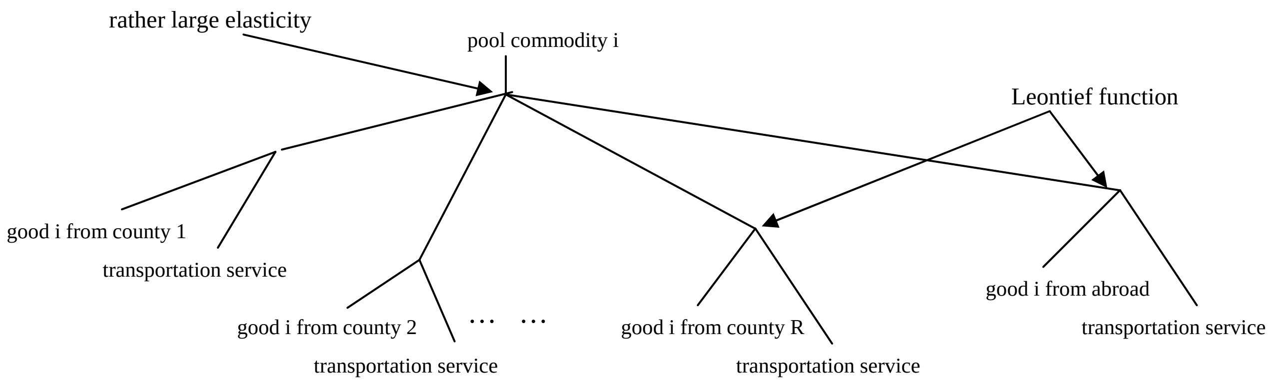

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Figure 2.6. Production tree for the commodity agents.

Two service agents in each county corresponding to the two types of services are represented in order to account for the difference between producer and consumer prices of the services. The amount of services produced by the service sector is in producer prices while the amount of services produced by the service agents are in consumer prices. The services produced by the agents are called pool services and they are used in the production of the commodities and in the production of physical capital. Transport connected with services is relatively minor as compared to transport of commodities and is not included in the first version of PINGO.

[3] Moses and Chenery (1990) introduced the so-called pooling concept.

2.3.5 Import/Export

The share of imported commodities depends on the price of imported goods including cost insurance and freight (CIF) as compared with the prices of domestic production, and of course the exchange rates.

Import and export activities are performed by the national import and export sectors. The export sector uses domestic commodities from different counties in order to produce the *trade balance commodity*, which may be thought of as foreign currency. It can be used to buy the imported goods or it can be saved as *national surplus* **.**

The import sector in its turn produces imported commodities using the trade balance commodity alone. The more goods are imported from abroad the greater is the demand for the trade balance commodity. The price of the trade balance commodity can be interpreted as the exchange rate between domestic currency and some aggregate of all foreign currencies. If the price level in Norway decreases relative to price levels in other countries, the exchange rate increases, hence there is less import and/or more export.

The activity level of the export sector is driven by the demand for the trade balance commodity, which in its turn depends upon the demand for imported goods. The greater is the demand of imported goods (which may be the case when labour endowments of the households are increased) the greater is the activity level of the export sector and amounts of exported domestic goods increase proportionally.

A trade balance deficit appears if the demand for import exceeds the value of the produced trade balance commodity. In this case the government imposes taxes on the production sectors and households in the amounts that finance the trade balance deficit.

However, the value of import cannot be much higher than the value of export since the government has limited possibilities to finance the trade balance deficit i.e. to produce the trade balance commodity.

2.3.6 Representative households

In PINGO there is neither distinction between the types of households nor the types of labour. There is one representative household in each Norwegian county in the model. Households income available for consumption comprise income from labour minus income taxes and taxes paid by the production sectors (i.e., social costs etc.), income from transfers[4] (social security) minus direct income tax, borrowings and profits earned from ownership in the production sectors, where the profit is the enterprises net of capital depreciation and new investments.

It is assumed that households use all income from available labour endowment to buy pooled commodities for consumption. Thus, the household’s operating surplus commodity represents all their incomes except wage that is used to buy pool commodities, i.e., transfers from the authorities, distributed profit of the sectors and income taxes, and some other income and spending of the households.

Commodities like cars, furniture, electrical units and clothes are assumed consumed in the year they are bought.

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[4] Transfers can be an important alternative or supplement for counties with weak production activities and weak income generation. Income generates purchasing power and consumption, which makes the foundation for production activities and employment, which may affect the regional development.

Representative household's preferences for different pool commodities provided by the respective commodity agents in each county are fully specified by their CES utility function that are fully described by representative consumption bundles and a zero elasticity of substitution between different commodities (Figure 2.7).

The households maximise their total utility constrained by the budgets, where the budget covers all costs of living including the services and housing rent, i.e., assuming non-satiation of the household's utility function the budget gives us its expenditure level.

It can be noticed that the utility functions do not include services. The reason is that there were no data available on the consumption of services by the households. But the present version of PINGO includes household's expenditures on services as part of the operating surplus commodity for consumers.

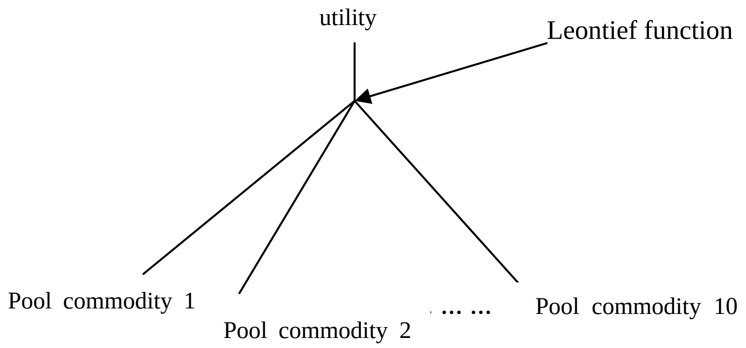

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Figure 2.7. Schematic view of the utility function for the county specific households.

2.3.7 Government sector

The national government sector is a balancing agent in the model. It produces/consumes both operating surplus commodities and trade balance commodity in amounts that clear the markets for these commodities. Production/consumption of the operating surplus commodities by the government sector is interpreted as subsidises/taxes for the respective counties. Production of the trade balance commodity is performed when it is necessary to finance the trade balance deficit and taxation of the counties. On the other hand when there is a trade balance surplus the counties may be subsidised**.**

2.4 Equilibrium conditions

We make the assumption that all economic agents in PINGO are well informed about all prices and act as the price-takers, and we assume that the producers adjust the prices in order to maximise profit, whereas the households are utility maximising consumers and owners of the labour endowments (see Appendix 1).

The profit maximising input-output coefficients $\mathbf{A}(\mathbf{P})$ are functions of prices **P** and production levels of all agents in the economy and are calculated per unit of production level. Let $\mathbf{A}(\mathbf{P})$ represent the general input-output matrix with coefficients for various goods in the economy, where each column include inputs (negative) and outputs (positive) in a sector (input-output vectors) and where rows includes all inputs and outputs of a factor.

We formulate PINGO as the following Mixed Complementarity Problem (MCP) where a vector $(\mathbf{P}^*, \mathbf{X}^*)$ with **P*** denoting prices of goods and **X*** denotes outputs, represents a general equilibrium in the economy if and only if:

(1) No activity earns positive profit: $-\mathbf{A}(\mathbf{P}^*)^T\,\mathbf{P}^* \geq 0$

(2) No commodity is in excess demand: $Q(\mathbf{P}^*) - R(\mathbf{P}^*) \geq 0$

(3) No prices or activity levels are negative: $\mathbf{P}^* \geq 0$, $\mathbf{X}^* \geq 0$

An activity earning negative profit is not operated and a non-zero activity level **y*** gives zero profit: $\left[-\mathbf{A}(\mathbf{P}^*)^T\,\mathbf{P}^*\right]^T \mathbf{y}^* = 0$,

(4) A commodity in excess supply is free, and a positive price implies market clearing by Walras' Law: $\left[\mathbf{Q}(\mathbf{P}^*) - \mathbf{R}(\mathbf{P}^*)\right]^T \mathbf{P}^* = 0$.

Equilibrium prices and activity levels $(\mathbf{P}^*, \mathbf{X}^*)$ are fully defined by the endowments of the consumers, which are the only exogenous variables that need to be fixed in the model and other variables that optionally exogenously set, e.g. prices on any good or labour can be fixed or endogenously determined.

2.4 Implementation

General equilibrium can be formulated as a system of non-linear equations and solved with a standard non-linear equation solver (see the example in the Appendix) or as a non-linear optimisation problem that is solved with the aid of general optimisation algorithms. Both methods have weaknesses. A better way of solving the problem is to formulate and solve the problem as a Mixed Complementary Problem (MCP) (Mathiesen, 1984).

MPSGE[5] software is used to implement and solve the first version of PINGO as a MCP. In the standard MPSGE model, utility functions are quasi-homothetic and production functions exhibit constant returns to scale.

The utility functions in MPSGE have the CES functional form and are fully specified by the demands in the benchmark situation and the elasticity of substitution between the goods. In the first version of PINGO the elasticity of substitution between consumption goods is supposed to be zero, i.e. CES functions are reduced to the Leontief form.

[5] MPSGE (*mathematical programming system for general equilibrium analysis*) is an extension of the GAMS programming language (Rutherford, 1995). MPSGE is a specialised for solving systems of equations that includes NCES-functions. The MPSGE Software is used to formulate and solve general equilibrium problems as "Mixed Complementary Problem" (MCP).

Production functions in MPSGE are represented by nested constant elasticity of substitution (NCES)[6] functions in order to merge two or more inputs into an intermediate product when the intermediate and not each basic input factor are used to create the final product. The NCES functions includes estimates of reference coefficients for the shares of the different input factors that specify a point on a specific isoquant or indifference curve, and estimates of the elasticities of substitution σ that gives us the curvature of the isoquant or indifference curve, and thus how the isoquant bends around the benchmark point, which is to say how the model responds to price changes.

MPSGE represents the output structure of production sectors in terms of constant elasticity of transformation (CET) functions, which are similar to CES functions. CET functions are fully described by the elasticities of transformation and reference coefficients for shares of output of each commodity and service.

When PINGO is formulated in the MPSGE programming language almost all variables in the model may be fixed or changed exogenously though in the concept of the Walrasian equilibrium the only exogenous variables are endowments of the households. This property of the program allows us to perform different kind of economic analysis with PINGO and gives it additional flexibility. Variables to be made exogenous are determined by the user according to the aims of his research. Some of the examples of possible exogenous variables and their use in the analysis performed with the model are given in test cases in Chapter 4.

MPSGE computes equilibrium prices and quantities when a model is properly specified in terms of production functions, utility functions, endowments etc. and the accompanying Social Accounting Matrix with one row for each commodity and factor input representing equilibrium between supply and demand.

The SAM is used for estimation of the representative share coefficients of the CES and CET functions in the MPSGE modelling system. The reference coefficients for the share of inputs and outputs are estimated in such a way that PINGO reproduces the economic situation in the base year 1999 (i.e., the SAM) if none of the exogenously given variables are changed. If some exogenous variables are changed, however, then PINGO find new values for gross production of each commodity in the counties, budget constraints in the counties, import shares of commodities to the counties, consumption of each commodity in the counties, transport of every commodity within and between the counties and between the counties and other countries and prices of commodities, services and labour, such that equilibrium is reached again in all markets.

While estimation of the reference coefficients for NCES and CET are performed on the basis of the data for the base year, the elasticities of substitution cannot solely be estimated on the basis of data from the base year. There can be need for time series analysis that is rather data and time consuming. That is why the elasticities of substitution were simply set at 0 (Leontief), 1 (Cobb-Douglas) or at some “qualified guess” in the first version of PINGO.

[6] NCES functions are briefly described in Appendix 1

3 Data in the Social Accounting Matrix

For a full-scale version of a SAM in PINGO, we must collect data for all sectors and commodity groups.

National Accounts Statistics present figures at market values that are subdivided in different value sets. There is a total of eight value sets. The producers price (18 values) is subdivided in (10=) basic value (non-zero for services), (11 =) VAT on the basic value, (12 =) special commodity taxes paid by the producer and (13 =) special commodity subsidies. The trade margin (19 values) is subdivided in (14 =) basic value of the trade margin (zero for services), (15 =) VAT on basic value of the trade margin, (16 =) special commodity taxes paid by wholesalers and retailers, and (17 =) subsidies connected with wholesale and retailing activities.

National Accounts Statistics report the gross production and the import in terms of producer prices (18 values), whereas the demand is valued in market prices (18+19 value). This means that the supplies and outputs part of the economy is valuated according to the basic value (10 value) which means that VAT, profit and taxes/subsidies are kept out, whereas the demands and inputs part of the economy is valued in market prices (18+19). Hence, the two parts of the economy are calculated in different value set.

The different value sets have the consequence that rows in the SAM matrix for the economy do not sum to zero. Understanding this fact it is possible to adjust the government supply or demand of the commodities in order to balance the SAM matrix, i.e., we calculate the values of elements for any i and r in the equations to balance the SAM for the benchmark situation, in such a way that $Q - R = 0$ (i.e., rows sums to zero).

Columns in the SAM matrix representing outputs and inputs of the production sectors and households should also sum up to zero. To ensure this we adjust operating surplus. A fully balanced SAM matrix corresponds to the equilibrium in the economy, i.e., rows and columns sum to zero.

3.1 Production

We have collected data for input and output in production from National Accounts by County (NAC) for 1997. The reason why we haven’t collected data for a later year (the base year is 1999) is that NAC is not available for later years. And since the NAC for 1997 is not complete, it has been necessary to separately collect some quantities to make a complete account for the commodities and sectors in PINGO. We do not consider this to be a serious inconsistency, however, since there were few structural changes in the Norwegian economy fro 1997 to 1999 and low inflation rate during this period.

Statistics Norway has aggregated the sectors and goods that are represented in NAC (174 sectors and commodities) to the PINGO-commodities and -sectors as specified by TØI**,** and gross production and inputs of commodities and services in every county. Inputs for production of physical capital (i.e., tangible assets) subdivided by PINGO-commodities for every county were obtained as part of the investment figures from NAC.

This includes figures for both the private and the public sectors. They are included as inputs in PINGO's investment sector for production of tangible assets (i.e., physical capital). From the data we were able to calculate the total output and input in Norwegian counties.

The valuation of the annual consumption of the 10 commodities according to market values amounts to 573 milliards NOK, where quantities that are not subdivided by county, mainly crude oil from the Continental shelf are not explicitly included. The total input to production of services that are subsequently used as inputs to produce commodities and other services amount to 492 milliards NOK where 312 milliards NOK are services and 180 milliards NOK is commodities (Table 3.1).

Table 3.1. Inputs to production of services that are subsequently used as input to production of commodities and other services

Commodities in PINGO Units	Service sector (N10) mrd NOK	Other sectors (N1-N9) mrd NOK	All sectors mrd NOK	Percentage in N10
1 Food	5	12	17	30
2 Fish	2	12	14	11
3 Thermo	6	34	41	15
4 Vehicles/machinery	56	47	103	54
5 general cargo	50	36	86	58
6 Timber and wood ware	17	10	27	62
7 Coal, sand and gravel	2	4	6	32
8 Chemical products	19	24	43	44
9 Metals and ore	5	36	41	13
10 Bulk commodities (liquid)	19	21	41	47
Inputs (commodities)	180	237	418	43
Inputs (services)	311	98	409	76
Total input	492	335	827	59

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The first version of PINGO do only represent production of services that are used as input to inland production of commodities and other services, but we have not made subdivision between services domestically produced and imported.

The value of input of commodities to the service sector amounts to 43 percent of the whole of the commodity input to the Norwegian economy. The service sector uses much timber and wood ware and general cargo (62 and 58 percent, respectively), but less commodities like fish, metals and ore and thermo (11 to 15 percent).

Table 3.2. Shares (percentage) of input to the service sector in different parts of Norway. The rightmost column shows how much the shares deviate relative to the population share in 1999

	Population share	Inputs to the service sector	Deviation from population share
Eastern – Norway	55	62	12,7
Western – Norway	26	29	10,2
Northern – Norway	19	10	-49,9
Norway	100	100	0,0

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The service sector (N10) is well represented in all counties, but to a greater degree in Oslo, Hordaland, Akershus and Rogaland, and to a lesser degree in Northern-Norway (Table 3.2).

The Foreign Trade Statistic (Statistics Norway, 1999) contains information about the amount of Norwegian import and export of commodities and which transport mode that is used to transport the commodity. The Foreign trade statistic represents data such that commodities for export change owner where the commodity is sent out of Norway (delivered ”free on board” – FOB), whereas commodities for import are represented such that the change of ownership takes place where the commodity is tolled in, i.e., cost insurance and freight is paid by the producer (CIF), which correspond to the conventions that are used for ”change of ownership” by the International monetary fond (IMF).

We have aggregated the commodity groups in the foreign trade statistic to NEMO – commodities, and we take advantage of the fact that the statistic were considerably improved from 1997 in that the production county for export were registered, as opposed to earlier statistics were only the place of tolling were registered.

3.2 Interregional delivery

The “SAM” – matrix includes elements for the value of goods that are transported between pairs of counties *ZL* and the corresponding transportation costs *TX*. We need to quantify the value of the transported commodities (basic values) and transport costs per ton commodity between and within counties.

Traditionally it would be difficult to obtain the data that are needed to estimate production functions for the national transport sector and the transport agents. However, with the aid of the national network model for freight transport NEMO (Vold et al., 2002) we may obtain the operating costs of transport between pairs of zones and transported volumes (tonnes) of each commodity between pairs of counties and between Norwegian counties and other countries in the base year. Production accounts for various transport operators for train, road and sea (obtained from Statistics Norway, 1999) made it possible to collect data for primary factors, commodities and services that are used as input to the national transport sector.

OD matrices for the tonnes transported between counties must be transformed to values. Using the following relationship to calculate the price per unit of commodity that is delivered from region r, and then use this price to transform from tonnes to value can do this:

$$p_{ir} = \frac{\sum_{j=1}^{10} X_{ijr}}{\sum_{r'} t_{rr'}^{i}}$$

where j denotes production sector, i denotes commodity group and r and r' denotes domestic counties or foreign countries and $t_{rr'}^{i}$ denote tonnes of commodity i transported between r and r'.

NAC report only net transport of each commodity group into (*ZM*) and out (*ZL*) of the counties. In such cases, we have that the total delivery of a commodity group out of plus into a county will be greater than the net commodity flow in NAC. However, since the commodities in NAC are relatively small, we have that separate aggregation of positive and negative commodity flows becomes close to the total flow in plus out, i.e., if commodities are very disaggregated it is more probable that they are produced in only one county. For import and export, we obtained separate values for import (*I*) and export (*A*) from the Foreign trade statistic (Table 3.3, 3.4).

There is also a county internal transport of pool commodities for consumption (*C*), and for use as input to production and for investments (*H*) (Table 3.5). For commodities where (Sum in + Sum intern – Sum out) is negative, we have that the commodities have a higher basic value than the price paid by the buyer (i.e., the market value). This implies that the sums of the values (components) from 11 to 17 are negative. This is typically a commodity that have a low profit and/or that are produced by a sector that receives subsidies. There can also be errors in the statistics. We have for instance not assessed the value of changes in stocks, i.e., that the commodity is produced, but is in storeroom and therefore are not sold. These changes are implicitly represented, however together with transfers etc. as part of the balancing factors (*G* and *GX*).

The reason for the low profit for food is probably due to some subsidies (agricultural subsidies is included in commodity trade in the national accounts, i.e., there are large negative 17 values)**.** Fish production is also subsidised, but these are far less since a great part of the fish is exported or further treated in industries. Further treated fish in vacuum packed or packed frozen is part of Food, since this commodity is sold directly in retail stores. For thermo goods, there are consumer subsidies as for food.

Vehicles/machinery has a large surplus since this is a commodity with both a high profit and high and specialised commodity taxes (12 value). This gives a small 10 value, which gives a surplus (Table 3.5). This is what one would expect for a typical situation for a balance of commodities, i.e., the 10 value is less than the 18+19 value (buyers cost). This situation is also representative for commodity 5 general cargos, commodity 8 Chemical products and for commodity 9, metals and ore. The reason for the large imbalance for commodity 10, liquid bulk products, is that this commodity is used as input in the continental shelf and the Norwegian military, which is not explicit part of the PINGO model.

Table 3.3. The aggregated commodity flow into the counties *(*ZM*)* and other countries *(*A*)* in market values (18+19 values). Mrd NOK.

PINGO commodity	Inputs	Export	Sum in
1 Food	17	2	19
2 Fish	14	20	34
3 Thermo	41	1	41
4 Vehicles/machinery	103	30	133
5 General cargo	86	28	114
6 Timber and wood ware	27	1	28
7 Coal, sand and gravel	6	0	6
8 Chemical products	43	22	65
9 Metals and ore	41	31	72
10 Bulk commodities (liquid)	41	19	60
Sum commodities 1-10	418	155	573

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The commodity *Timber and wood products* and the low value commodity *Coal, sand and gravel*, there are large negative values that are not caused by subsidies. These can be commodities that are not sold, but stored. A more likely explanation, however, is that the majority of commodities of this kind is delivered to entrepreneurs in the investments sector and that the input flows were not accounted for in CNA 1997. We have for instance that the new national airport Gardermoen were under construction in 1997 with a large production bulk products that were delivered to this project. NA for Norway do not account for these investments until the project is finalised.

Table 3.4. The aggregated commodity flows from the counties (production) (*ZL*) and imports of commodities to counties (*I*). All figures are valued in basic prices. Milliards NOK.

PINGO commodity	Import	Production	Sum out
1. Food	8	91	99
2. Fish	3	36	38
3. Thermo	4	66	69
4. Vehicles/machinery	94	15	110
5. General cargo	76	100	177
6. Timber and wood ware	4	35	38
7. Coal, sand and gravel	2	50	52
8. Chemical products	22	19	41
9. Metals and ore	8	19	27
10. Bulk commodities (liquid)	5	2	7
Sum commodities 1-10	225	433	658

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Table 3.5. Commodity flows into the counties, intern (18+19) values, internal and out of counties (Milliard NOK)

PINGO commodity	Sum inn (18+19)	Sum intern (18+19)	Sum ut (10)	Inn + intern – ut
1. Food	19	52	99	-28
2. Fish	34	4	38	-1
3. Thermo	41	10	69	-18
4. Vehicles/machinery	133	168	110	191
5. general cargo	114	121	177	58
6. Timber and wood ware	28	2	38	-9
7. Coal, sand and gravel	6	0	52	-46
8. Chemical products	65	12	41	37
9. Metals and ore	72	1	27	46
10. Bulk commodities (liquid)	60	34	7	87
Sum commodities 1-10	573	404	658	318

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3.3 Consumption

There were 2 049 000 households in Norway in 1999 (Statistics Norway, 1999). Total consumption cost (services and commodities) were 268 514 NOK per household in 1999. Total Private consumption amounts to about 548 milliard NOK (46 percent of the GDP in Norway) in 1999, where 305,6 milliard NOK was consumption of commodities and the rest was consumption of services (Figure 3.1).

We applied data from the Consumption survey for private households of Statistics Norway to estimate the total consumption in the years 1998-2000 per household in (1)

Akershus and Oslo, Hedmark and Oppland, (2) the rest of the counties in South-Eastern Norway, (3) Agder and Rogaland, (4) Western Norway, (5) Trøndelag and (6) Northern Norway. The average shares of total consumption in the counties for each of the commodities and services were then used to get the total consumption costs for each of the commodity groups in the counties (Table 3.6).

Table 3.6. Consumption expenditure and investments in Norway (milliard NOK in 1999) subdivided by PINGO-commodties as measured in 18+19 values (milliard NOK)

PINGO commodity	Private consumption	Investments	Sum intern
1. Food	52	0	52
2. Fish	4	0	4
3. Thermo	10	0	10
4. Vehicles/machinery	71	97	168
5. general cargo	116	5	121
6. Timber and wood ware	0	2	2
7. Coal, sand and grave	0	0	0
8. Chemical products	12	0	12
9. Metals and ore	0	1	1
10. Bulk commodities (liquid)	34	0	34
Sum commodities 1-10	300	104	404

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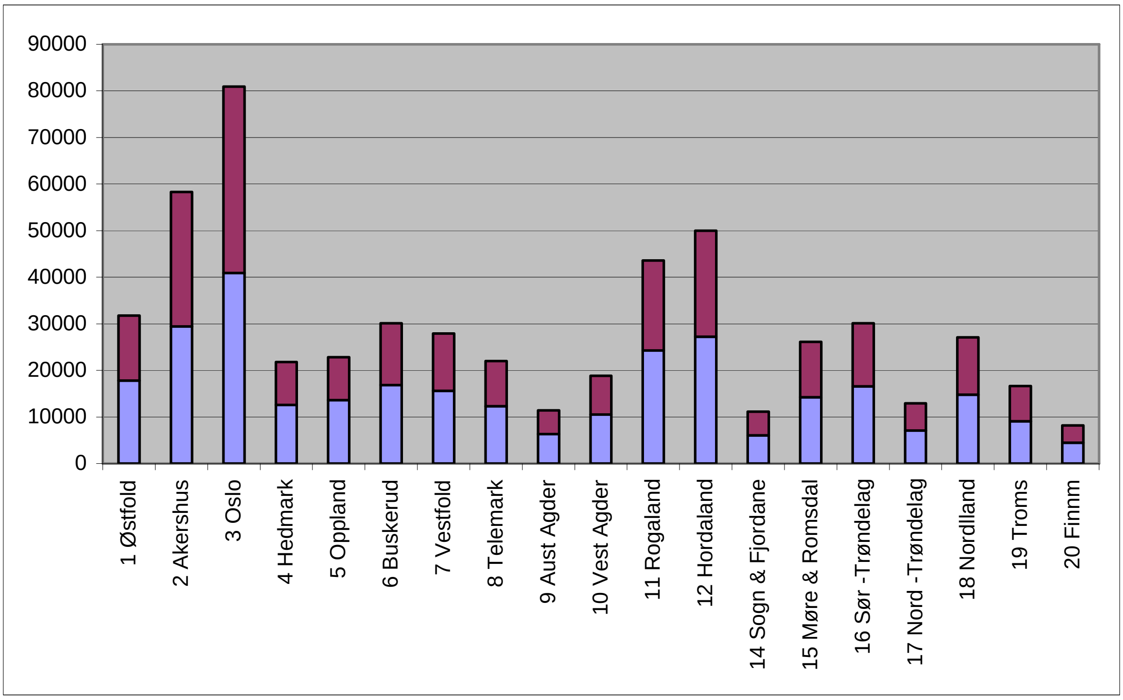

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Figure 3.1. Total private consumption of commodities (lower part of bars) and services in the counties.

4 Test cases

PINGO allows us to carry out many different types of simulation experiments, and to conduct a comprehensive investigation of the economic adjustment processes induced by assumptions about external shocks or by specific hypotheses of economic growth. In order to verify PINGO we may identify whether the model assesses casual relationships among variables and relative magnitudes of variables that are reasonable from a theoretic and intuitive point of view.

There are broadly two classes of simulation experiments for verifying PINGO:

1) Simulations based on the adoption of values for exogenous variables that are different from their values in the benchmark situation.

2) Simulations based on the modification of system parameters relative to values used for the benchmark situation.

The first class includes:

- Changes in available labor endowments in the counties.
- Changes in prices on selected domestically produced or imported commodities.
- Changes in prices on transport or other services.

The second class includes:

- Technological progress and change in the input/output mix
- Adoption of investment plans in transport infrastructure affecting transportation costs and/or carrying capacities
- Changes in consumer tastes
- With the operating surplus commodity it is possible to demonstrate consequences of changes in regional policy.

We have run four test cases for verification of the first version of PINGO. For each test case we report changes in total production and consumption in the counties and freight transport flows between counties as relative to the benchmark situation. Import and export is additionally reported for test case 3.

We also need to report the average distance per unit of goods transported. In lack of a directly available indicator for the average distance, we used the proxy (in NOK):

$$\Sigma = \frac{\sum_{i,j,k} t_{ij}^{k} c_{ij(base)}^{k}}{\sum_{i,j} t_{ij}^{k}},$$

where t_{ij}^{k} is the amount of goods of type *k* in tons transported from county *i* to county *j* and $c_{ij(base)}^{k}$ is the base-case costs of transporting volumes of goods of type *k* from county *i* to county *j*, which is a proxy for the distance between counties *i* and *j*[7].

For the base-case we have that $\sum = 280.17$ NOK.

In *Test case 1*, we applied PINGO for a situation where labour endowment in Oslo increases by 6% relative to the benchmark situation. This increase production (Figure 4.1), and result in a sharp increase in transportation flows originating in Oslo (Figure 4.2). The increase in production in Oslo stimulates production growth in counties that are connected with Oslo through interregional trade, which have the effect that transportation flows that originate and terminate in these counties increases (Figure 4.2 and 4.3).

It is interesting to notice, however, that the total consumption in the Oslo County goes down (Figure 4.4), which is due to reduced price of labor relative to prices of pool commodities in Oslo. Increasing consumption prices can be explained by the fact that there is no substitution between intermediate goods and labor (i.e., Leontief technology, see section 2.3.2), which does not allow the sectors to substitute intermediate goods with now cheap labor and increase production in order to meet increasing demand.

The proxy for average distance becomes $\Sigma_{case1} = 280.399$ NOK, which indicates a small increase in the transportation distance per ton of commodity.

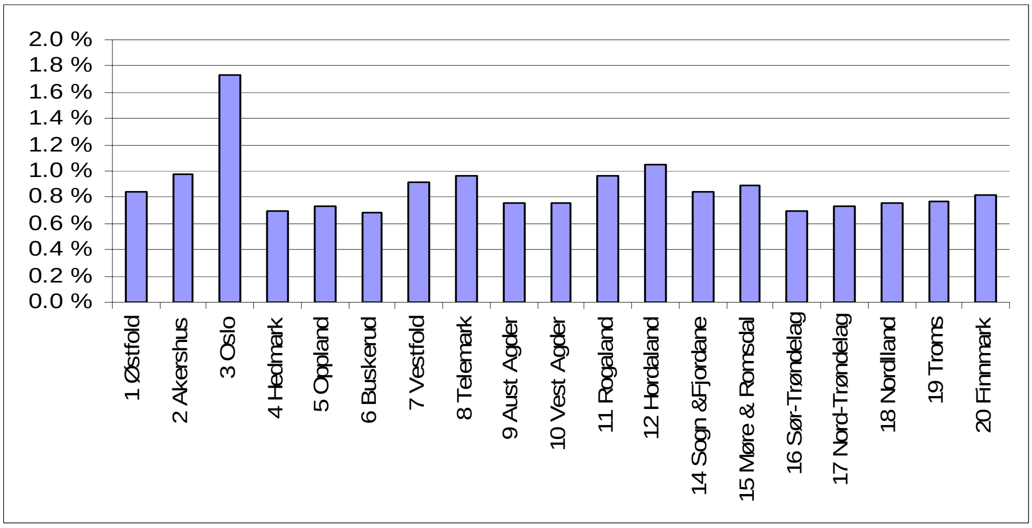

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Figure 4.1. Change in total production by county.

[7] It is noted that transport costs from other countries to Norway are constant in PINGO.

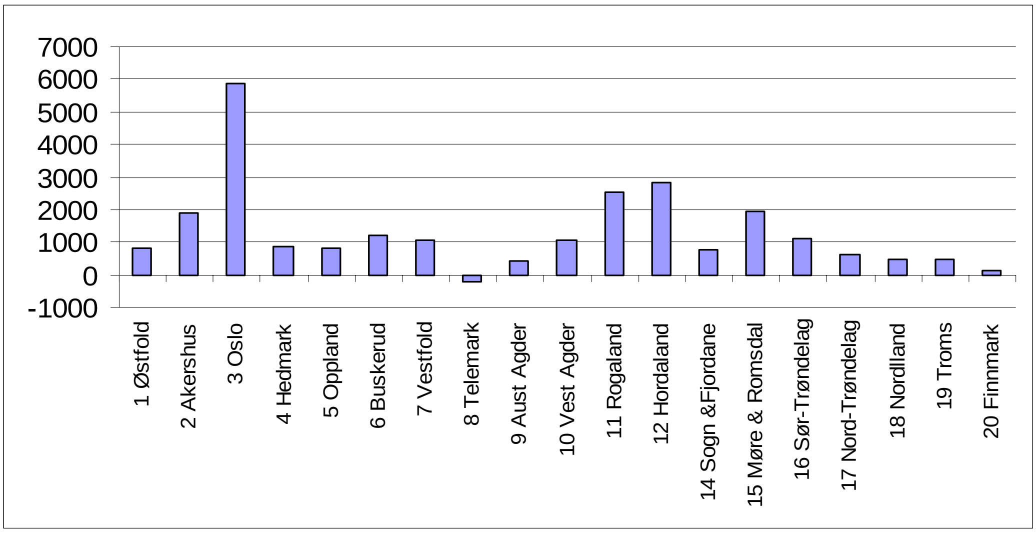

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Figure 4.2. Changes in transportation flows that originate in the counties (1000 NOK).

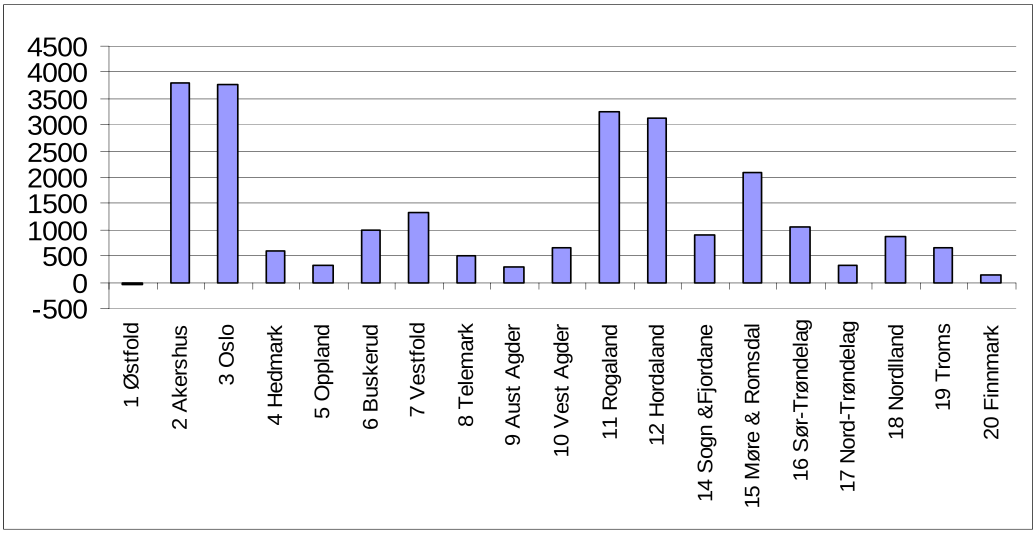

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Figure 4.3. Changes in transportation flows that terminate in the counties (1000 NOK).

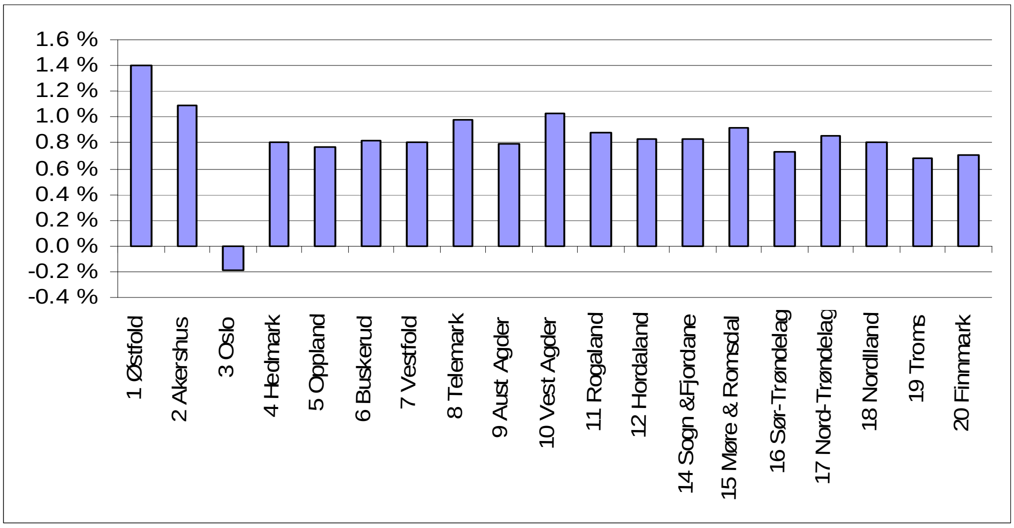

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Figure 4.4. Percentage change in total consumption by county.

Test case 2 differs from the previous test case in that we increase labor endowment by 5% not only in Oslo but also in all other counties. The results show that the overall increase in labor endowments leads to increased production in all the counties (Figure 4.5) and corresponding changes in transportation flows originating from and terminating in the counties (Figure 4.6 and 4.7). Most of the increase is located in Akershus, Oslo, Rogaland and Hordaland. We may conclude that the model correctly predicts that these counties are the most economically important, and the ones that are associated with the largest transportation flows.

The changes in the absorption of transportation flows are a bit different from those of Test case 1, which can be due to the fact that the distribution of the population over the country does not correspond to the distribution of production activities.

Consumption in the counties is positively affected as demonstrated in Figures 4.8. An exception is Oslo, where the total consumption has been reduced. The explanation for the negative change in household incomes and consumption in Oslo is probably the same as for Test case 1, and that other counties produce more of their needs themselves when their available labour endowments increases and that Oslo is more negatively affected since its wages constitute a greater share of the household income.

The reason for a reduction of the proxy for the average transport distance $\Sigma_{case2} = 279.029$ NOK, can be that nearby counties produce a greater part of the commodities, which gives less need for long-distance transportation.

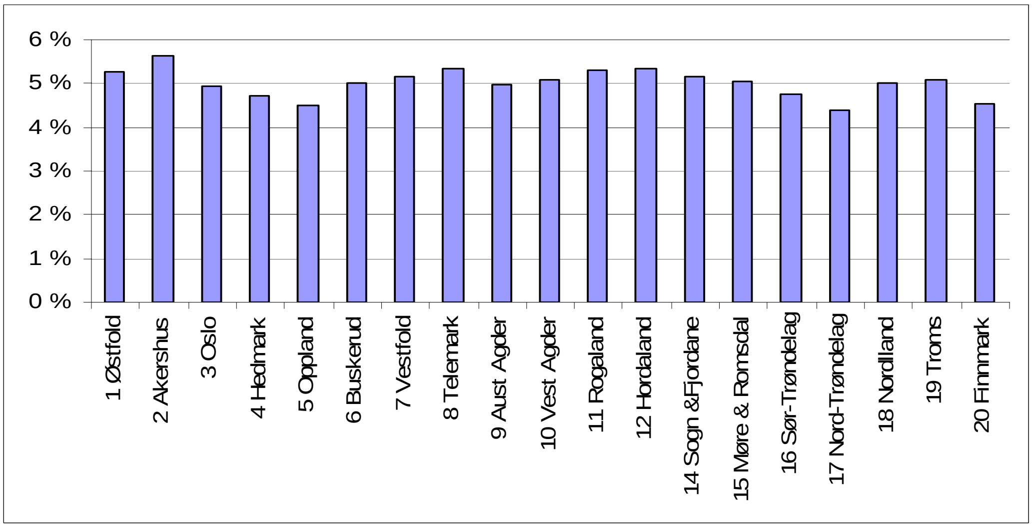

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Figure 4.5. Change in total production by county.

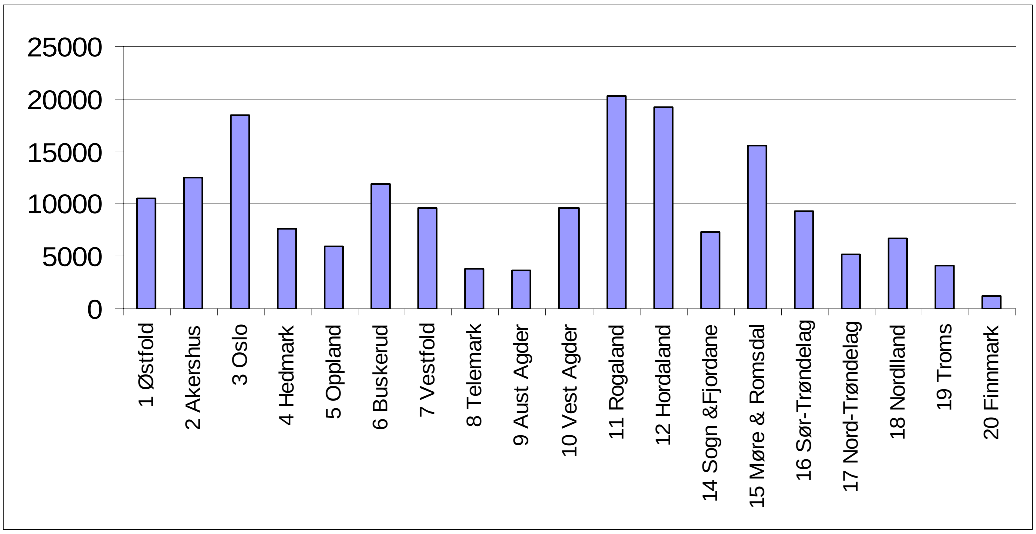

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Figure 4.6. Changes in transportation flows that originate in the counties (1000 NOK).

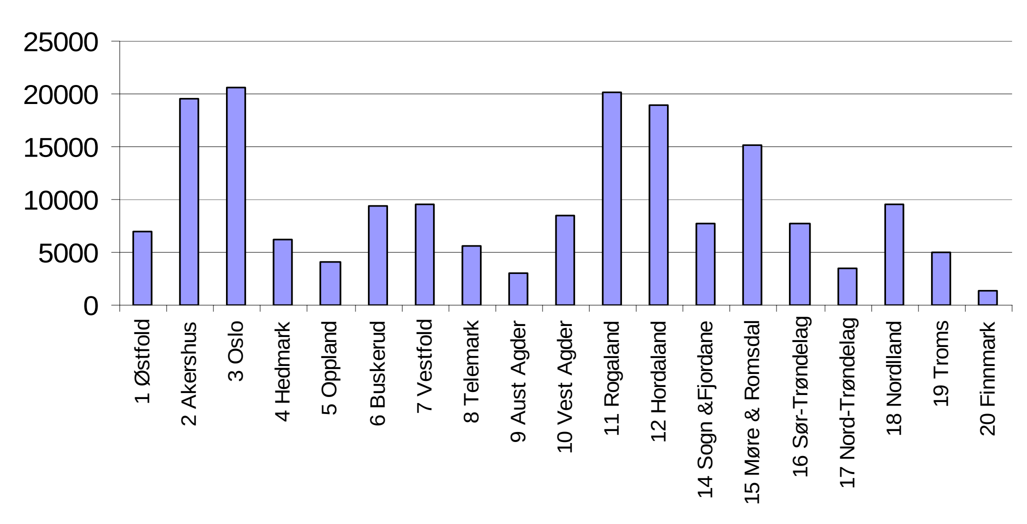

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Figure 4.7. Changes in transportation flows that terminate in the counties (1000 NOK).

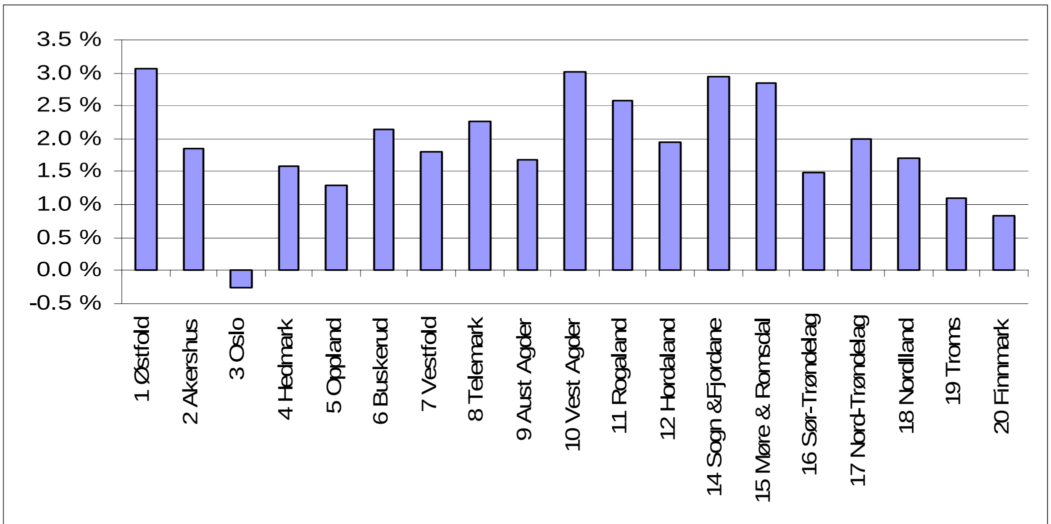

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Figure 4.8. Percentage change in total consumption by county.

Test case 3 was run in order to investigate the effect that a 5% increase in the price of imported goods will have on the transportation flows (e.g., added import tax). An overall effect is the reduction in imports going to all the counties relative to the benchmark situation (Figure 4.9). The greatest effects are found for Østfold, Akershus and Oslo respectively, which is reasonable, since these are the counties that are associated with the largest shares of the total imports. The percentage change in import for the counties is quite similar (about - 4.5 %), except for Troms that has and 8% reduction in imports (Figure 4.10). The increased price on imported goods reduces production and transportation flows, except for Østfold where production and originating and terminating transportation flows increases (Figure 4.11, 4.12 and 4.13). However, consumption is reduced in all counties (Figure 4.14). The average distance of transportation was reduced: 279.76 NOK.

The anomalous results for Østfold may be due to Østfold's role as a transit point for much import to other counties and that the model due to the lack of necessary data does not reflect this empirical fact. The anomalous import to Østfold gives a benchmark situation with incorrectly high consumption in the private households in Østfold, and the effect that private consumption includes an incorrectly high share of imported commodities. Higher import prices reduce demand for import and increase the demand for domestically produced commodities (administrated by the commodity agents). This have the consequence that a greater part of household's income in Østfold is used for domestically produced goods, whereas the artificially high government subsidies to households to finance the artificial import to Østfold (which is actually transit import to other counties) in the benchmark situation are reduced. The reduction in artificial subsidies reduces households income, which have the consequence that consumption goes down, but total production and total transportation within Østfold and between Østfold and other regions increases due to increased demand for domestically produced goods.

In conclusion then, a small correction must be made in order to make the model respond adequately to changes that affects import. One way of doing this would be to construct a SAM were imports are distributed directly to the county where it is consumed or used as input.

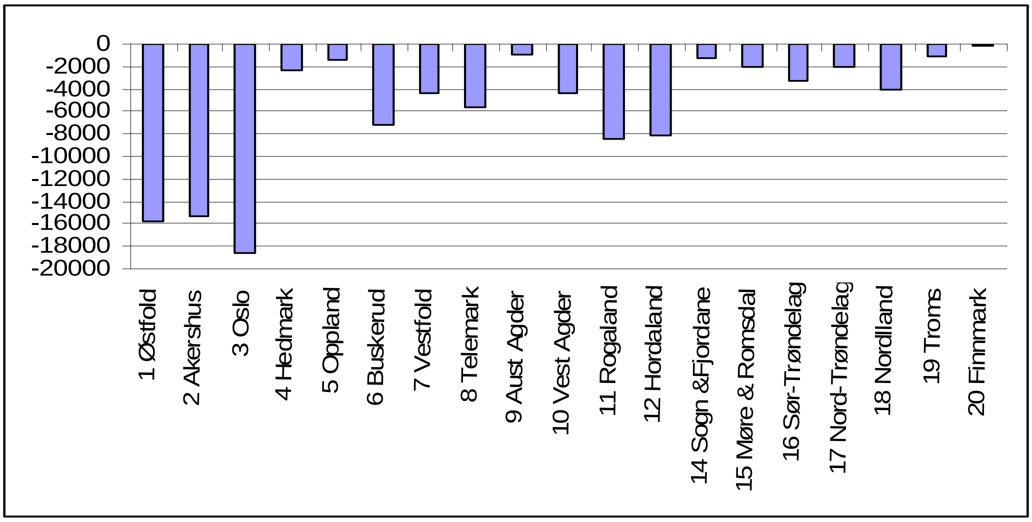

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Figure 4.9. Changes in imports to the counties (1000 NOK).

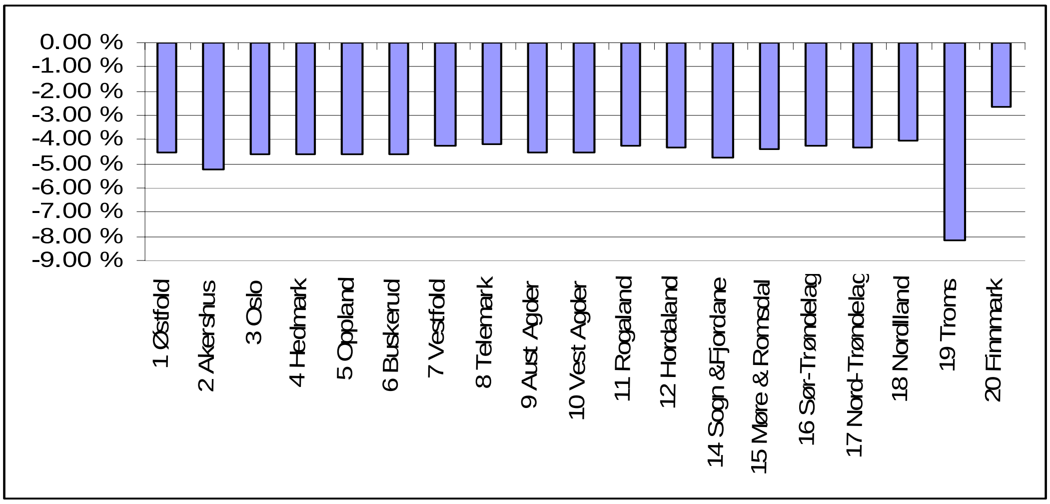

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Figure 4.10. Percentage changes in imports.

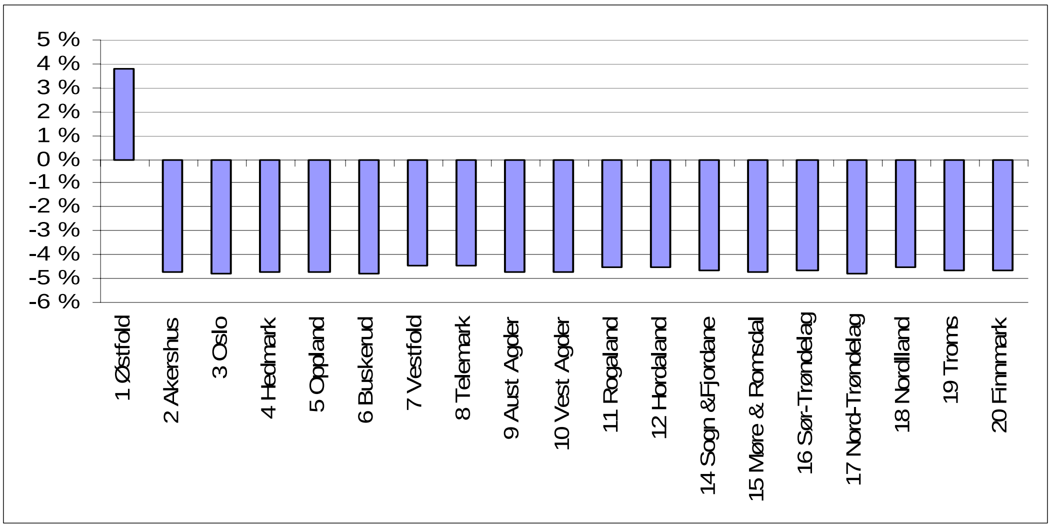

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Figure 4.11. Percentage change in production by county.

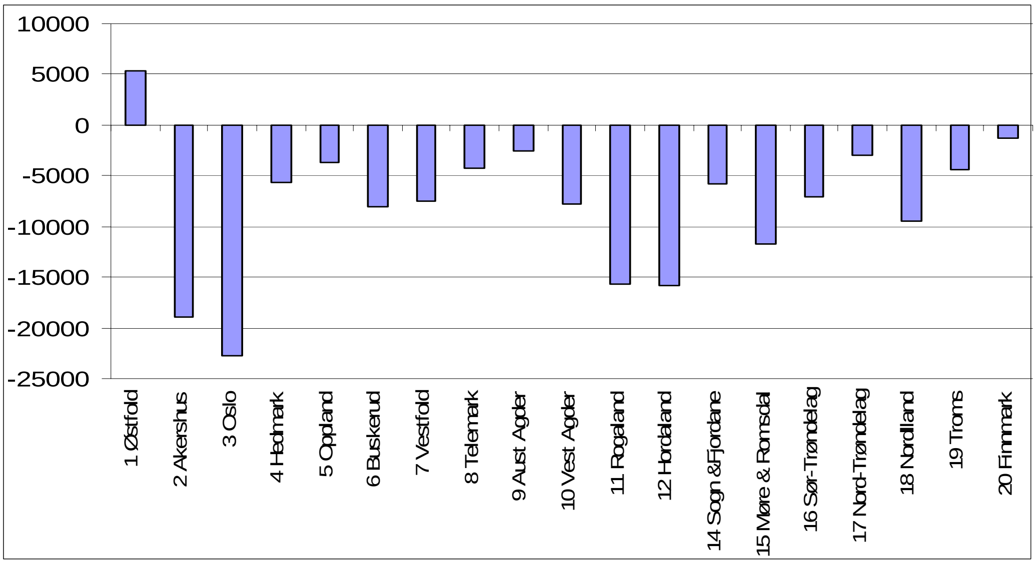

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Figure 4.12. Changes in the transportation flows (1000 tons) that terminate in the counties.

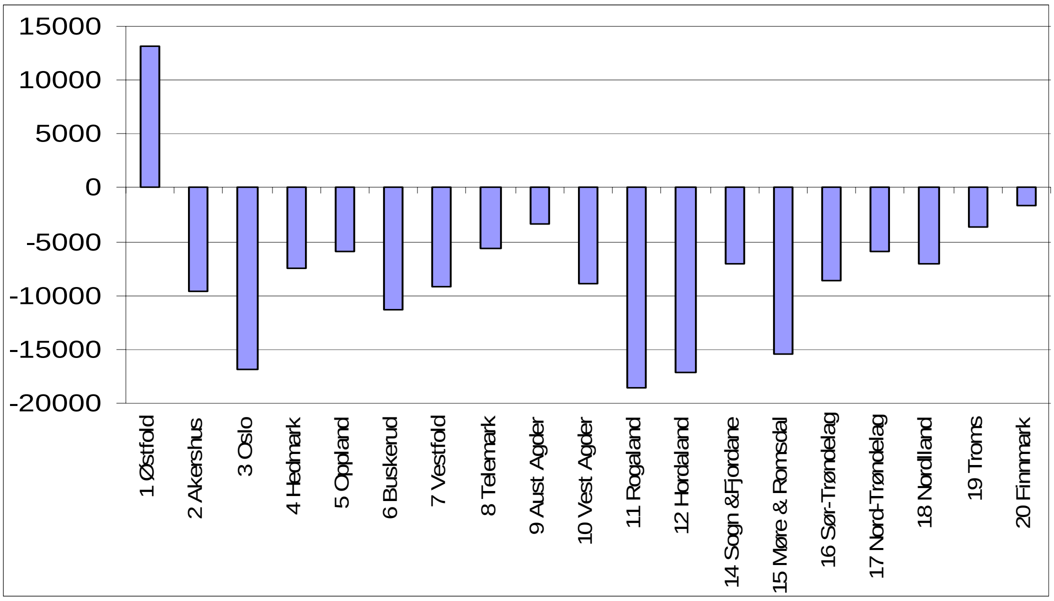

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Figure 4.13. Changes in the transportation flows (1000 tons) that originate in the counties.

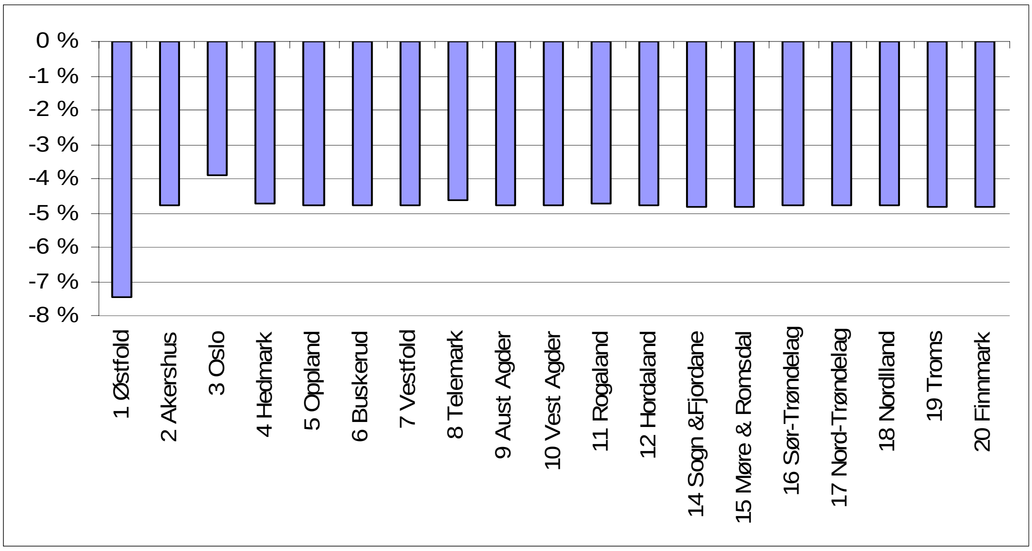

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Figure 4.14. Percentage change in consumption by county.

In *Test case 4* we investigate the effect of a 2% increase in the price of commodity group 10 (bulk commodities), which includes petrol and oil that are important inputs in the transportation sector. There is a reduction in production and originating and terminating transportation flows for all counties, except for Østfold, whereas consumption is reduced for all counties (Figures 4.15, 4.16, 4.17 and 4.18). These anomalies are due to the same problems that were outlined under the description of test case 3, i.e., increasing transport prices gives less demand for imported goods, this increases the demand for domestically produced commodities and so on. There is a small reduction in the proxy for average transportation distance: 280.323 NOK.

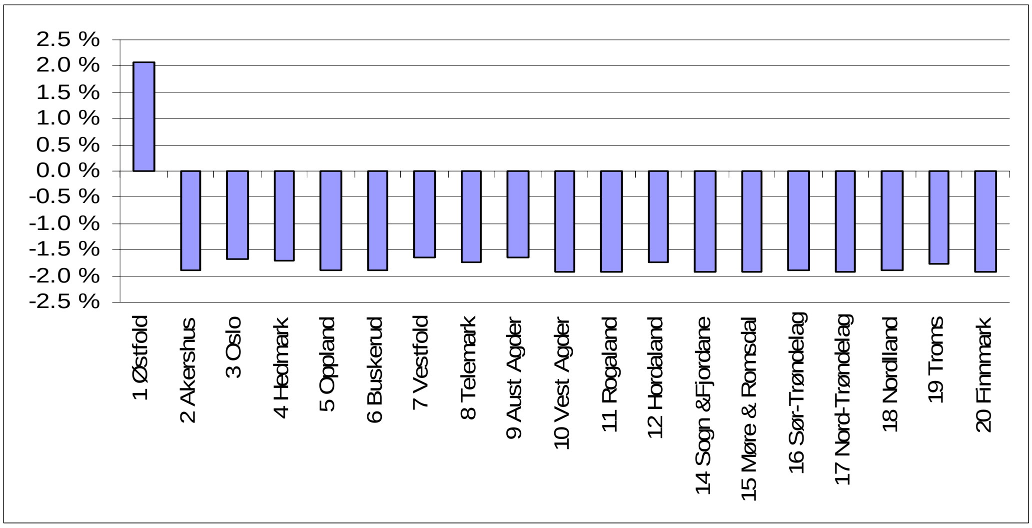

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Figure 4.15. Percentage increase in production by county.

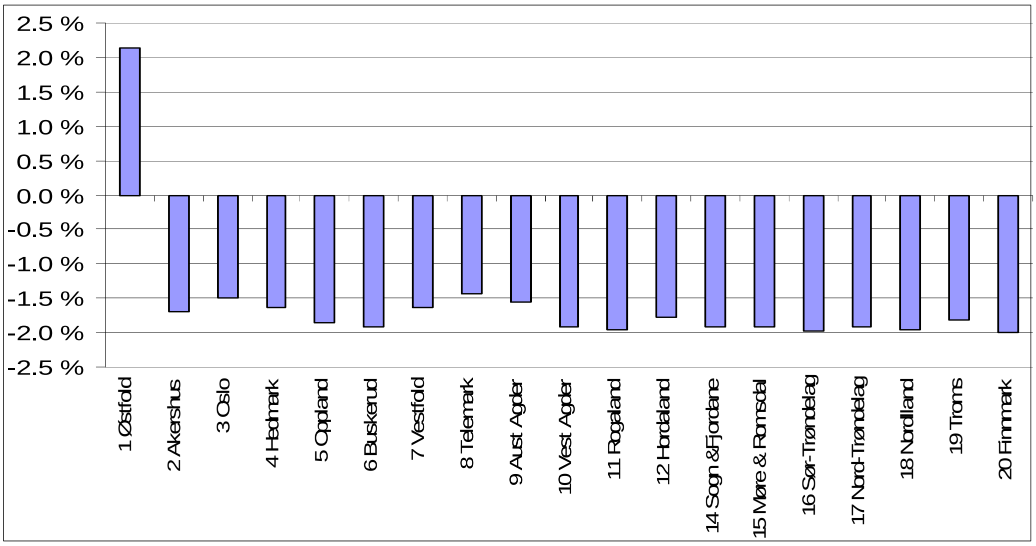

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Figure 4.16. Percentage changes in transportation flows (tons) to the counties.

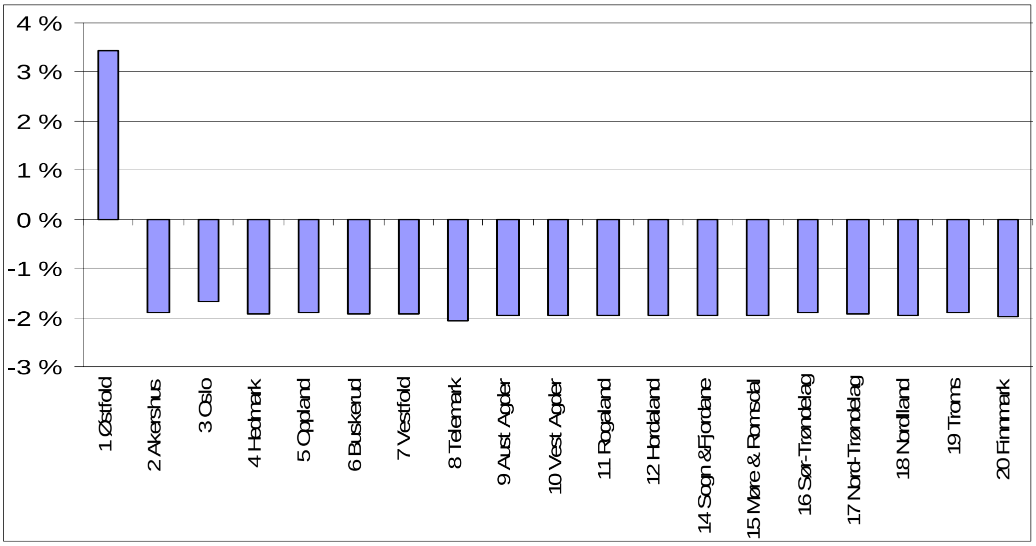

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Figure 4.17. Percentage changes in transportation flows (tons) originating in the counties.

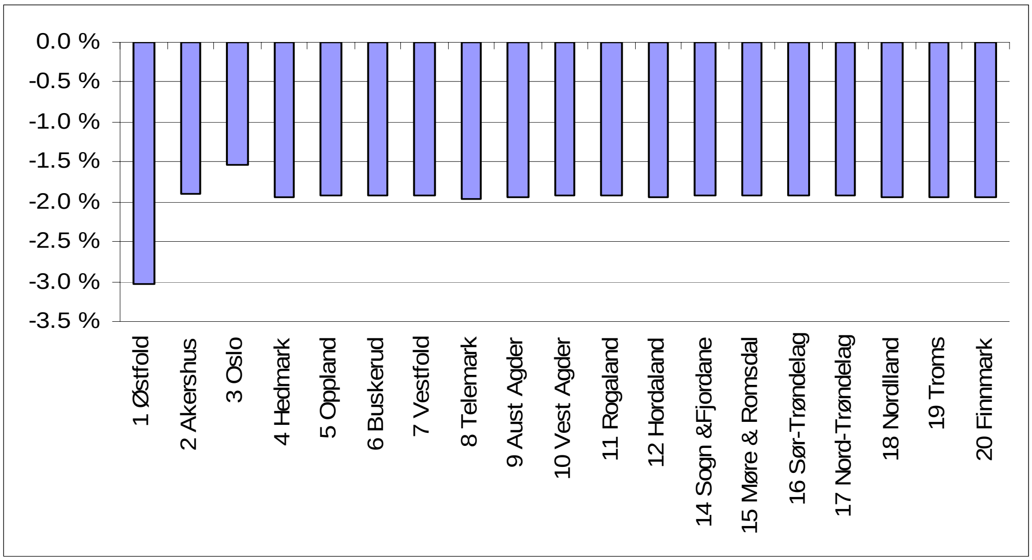

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Figure 4.18. Percentage changes in consumption by county.

5 Forecasts

Growth rates are needed in order to project OD matrices from NEMO for freight flow (tonnes) from the base year 1999 to target years in the future.

In order to apply PINGO to produce such growth rates, we have to decide "to what degree" we want to use PINGO as a bottom-up or top-down model.

A bottom-up approach would be to apply exogenously given forecasts for labour endowments in PINGO and then use the resulting production and consumption in the counties as forecasts. In lack of forecasts for labour endowments in the counties, we may make the assumption that the relative change in the available labour in the counties is proportional with a weighted sum of the share of available labour in the benchmark situation in the counties $\frac{n_r^0}{\sum_r n_r^0}$ and the share of population growth in the counties $\frac{\Delta g_r}{\sum \Delta g_r}$. Thus, if the total change in labour endowments is Δn, then the change in labour endowments in the counties can be expressed by

$$\Delta n_r = \left(\alpha \cdot \frac{n_r^0}{\sum_r n_r^0} + \beta \cdot \frac{\Delta g_r}{\sum_r \Delta g_r} \right) \cdot \Delta n .$$

With a bottom-up approach we run the risk, however, that there can be considerable deviations between the national production and consumption obtained from national models and corresponding figures from PINGO.

A pure top-down approach would assure that the sum of production and consumption from PINGO equals corresponding figures from national models like MSG and MODAG. Adjusting labour endowments for each county such that there is coherence between the total production and consumption of each commodity group in a national model and PINGO can do this.

It is not obvious, however, how to do the adjustment. A less ambitious task would be to assure coherence for the rate of increase of total production only, which could be characterised as something in-between bottom-up and top-down.

We may assume that the production of commodities in each county is increasing according to the growth rates received from the MSG model. We would then like to find county specific labour endowments, which correspond to these growth rates. To perform the task we change the unknown variables in the formulation of PINGO (see section 2.4), so that labour endowments play the role of the unknowns while activity levels of the sector are known and derived from the forecasted growth rates. In order to be able to use MPSGE to solve PINGO in the new formulation it is necessary to interpret production sectors as the consumers with fixed endowments of produced goods and households as firms, which produce labour endowments using consumption goods.

The projected matrices are used as input to NEMO, where the OD matrices for the total transport volumes are distributed to OD matrices for different transport modes.

6 Future perspectives

This report describes the first version of the SCGE model PINGO and a simple verification of this model. This first version can be developed further in many respects to improve reliability:

- Estimation of elasticities
- Improve import
- Mobility of physical capital and labour
- Segmentation of household groups
- Economies of scale
- Better forecasts

One possible way to further develop the model would be to improve the elasticities of substitution either by literature studies and surveys or by econometric techniques with available time series data to estimate the elasticities of substitution between inputs and outputs for the production functions and the elasticities of substitution between demands for the utility functions of all economic agents in the model. Of major interest in this respect is the elasticities that govern the change in the shares of commodities that are delivered from other counties, where we would have to consider how transport cost reduction would changes the logistic systems of the firms.

A small correction would make the model respond more adequately to changes that affects import. In order to do this one should construct the SAM were import is distributed directly to the county where it is consumed or used as input. The problem here is the availability of necessary data.

In the first version of PINGO, we have assumed that physical capital labour cannot move between counties. In reality there is a migration between counties as well as immigration to Norway from other countries, where the households may either move or commute to new work places. It would be worthwhile to construct a new sub model in PINGO for allocation of physical capital and labour in the counties according to the Nash equilibrium (Varian, 1992).

Segmentation of the households according to income or labour groups and thus different consumption patterns would make it possible to analyse distributional effects.

Producers in the present version of PINGO exhibit constant returns to scale and there is a perfect competition in the economy. Returns to scale and market power influence the level of production and prices; hence they are essential for determining goods flows between counties. Inclusion of more realistic mechanisms in this respect would probably improve the reliability of PINGO.

Transport infrastructure is the scare economic resource provided mainly by the government and it has a certain capacity. However capacity constraints are not present in PINGO. A possible way to include capacity constraints would be to model congestion through the decreasing returns to scale production technology of the transport sector, so that after some level of output transport services become more and more expensive to produce. Another solution is to integrate transport network and Wardrobian equilibrium into the general equilibrium framework. It is possible since both general equilibrium and Wardrobian equilibrium may be formulated as a mixed complementarity problem and solved simultaneously.

None of the proposed methods in chapter 5 for how to use PINGO to project OD matrices from a base year to a future benchmark year were true top-down approaches. For a true top-down approach, a more advanced method is needed, which would include assurance of coherence not only for production and consumption, but also for export/import and the use of commodities and services as input to production. An in-depth study of methods for how to use PINGO with top-down approaches is needed to improving the suggested methods to set up a future benchmark year with PINGO.

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Appendices

Appendix 1: CES functions

A.1.1 CES production functions

CES ("constant elasticity of substitution") is a class of functions that are suited for modeling of general equilibrium. The CES functions that are used in PINGO describe constant return to scale. The CES functions includes constant elasticities of substitution that govern to what degree the shares of the inputs are changed with respect to price changes. We formulate a general CES-function by

$$X_{ir} = f(\mathbf{H}) = \gamma_{ir} \left(\sum_{j \neq i} \alpha_{jr} H_{jr}^{\rho} \right)^{\frac{1}{\rho}} ,$$

where γ_{ir} is a scale parameter, α_{jr} is a reference coefficient for the share of input where $\alpha_{jr} > 0$ and $\sum_{j \neq i} \alpha_{jr} = 1$. It can be shown that $\rho = \frac{\sigma - 1}{\sigma}$, where σ is an elasticity of substitution, which again imply that $\sigma = \frac{1}{1-\rho}$. The CES functions are linear homogenous (of degree 1). One can therefore calibrate the CES function by letting the expression $\left(\sum_{j \neq i} \alpha_{jr} H_{jr}^{\rho} \right)^{\frac{1}{\rho}}$ express the production of a single unit of the commodity group *i*. From this, we may let the initially (observed) production volume, X_{ir}, be represented by the scale parameter γ_{ir}.

If the elasticity of substitution is set at zero then we get the Leontief function

$$X_{ir} = f(\mathbf{H}) = \min_{j} \left[\frac{H_{jir}}{\alpha_{jr}} \right],$$

which gives a inelastic use of input factors if we assume cost efficient production. With Leontief, we get a system that is non-sensitive to price changes with fixed shares of input factors.

If we use elasticities of substitution equal to one, we get the Cobb-Douglas function

$$X_{ir} = f(\mathbf{H}) = \gamma \cdot \prod_{k} H_{kir}^{\alpha_k}$$

which gives that fixed shares of the budget is used for each input factor in optimum, i.e., there is a fixed share of the budget that is used to cover the cost of each input factor.

A.1.2 Profit maximization and utility maximization with CES functions

Consumption is determined by maximising a CES utility function with respect to quantities of each commodity consumed under the budget constraint:

$$\max_{C_{1r}^{1},...,C_{I}^{I}} U^{r}(C_{1r},...,C_{Ir})$$

such that $\sum_{i=1}^{I} C_{ir}(P_{ir}) = L_{r}(P_{labour})$,

where U^r is a CES function representing the consumers utility function in county r with respect to county specific pool commodities, and L_r denotes labour endowment (all income) for representative household in county r. As a result of utility maximization at given prices of county specific pool commodities $\tilde{P}_{ir}$, we get the household's demand functions $d_{r}^{i}(L_{r}(P_{labour}),\tilde{P}_{1r},...,\tilde{P}_{Ir})$.

We assume that the profit-maximizing producer is constrained by the production possibilities

$$\underset{X_{ir},\mathbf{H}}{Max}\left[P_{ir}\cdot X_{ir}-\sum_{l} P_{lr}\cdot H_{lir}\right]$$

Profit maximization is found by solving the equation obtained by setting the derivative equal to zero (Gravelle & Rees, 1993, s.231). First order conditions becomes:

$$P_{kr}+P_{ir}\cdot\frac{\partial f_{ir}}{\partial z_{k}}=0 \quad \forall k$$

If the product function is of the Cobb-Douglas type, then we get

$$P_{kr}+P_{ir}\cdot\left[\gamma\cdot\alpha_{kir}\cdot H_{kir}^{(\alpha_{kir}-1)}\cdot\prod_{l} H_{lkr}^{\alpha_{lir}}\right]=0 \quad \forall k$$

If we set $P_{ir}=C_{ir}(\mathbf{P})$, we get

$$H_{kir}=\frac{X_{ir}}{\gamma}\cdot\frac{C_{ir}(\mathbf{P})\cdot\gamma\cdot\alpha_{kir}}{P_{ki}},$$

where the cost function C_{ir} is determined by solving the cost minimization problem:

$$\underset{\mathbf{H}}{Min}\sum_{l} P_{li}\cdot H_{lir}$$

s.t

$$X_{ir} = f_{ir}(\mathbf{H})=\gamma\cdot\prod_{k} H_{kir}^{\alpha_{kir}}$$

A solution to this problem is given by (Varian, 1992, p.54)

$$C(P_{ir}) = \frac{1}{\gamma} \cdot \prod_l \left(\frac{P_{lr}}{\alpha_{lir}} \right)^{\alpha_{lir}}$$

where the scale factor γ express observed production in a the base case situation $\hat{X}_{ir}$. While we use the estimates

$$\hat{C}_{ir} = \sum_l \hat{P}_{lr} \cdot \hat{H}_{lir}$$

and

$$\hat{\alpha}_{kir} = \theta_{kir} = \frac{\hat{P}_{kr} \cdot \hat{H}_{kir}}{\sum_l \hat{P}_{lr} \cdot \hat{H}_{lir}},$$

it is easily shown that the share of input factors can be expressed by

$$H_{kir} = \frac{X_{ir}}{\hat{X}_{ir}} \cdot \frac{C_{kir}}{\hat{C}_{kir}} \cdot \frac{\hat{P}_{kir}}{P_{kir}} \cdot \hat{H}_{kir}$$

and that the unit cost for production of a commodity can be expressed as

$$C_{kir} = \frac{\hat{C}_{kir}}{\hat{X}_{ir}} \cdot \prod_l \left[\frac{P_{lir}}{\hat{P}_{lir}} \right]^{\hat{\alpha}_{lir}}.$$

If there are no limiting use of input factors, then the production are described as "constant return to scale". Some inputs or factors can be exogenously given, however, for instance labor. If a factor is exogenously given, then the price of the factor is given as the derivative of production functions with regard to the use of the factor $\frac{\partial f_{ir}}{\partial H_{kir}} = P_{kr}$. For a Cobb-Douglas function, the price of a constant amount of labor H_{kir} for production of a given commodity becomes:

$$P_{kr} = \gamma \cdot \frac{1}{H_{kir}} \cdot \alpha_{kr} \cdot \prod_l H_{lir}^{\alpha_l}$$

If there are limits in the use of input or factors, then the production has increasing return to scale. When the producer reach the capacity limit for one or several inputs or factors, then he may only use the other inputs or factors to increase the production which have the consequence the price of the limited factors increases exponentially.

A.1.3 Nested CES functions

Application of nested CES functions in order to assess production output with respect to inputs can be represented in terms of three structures (Figure A.1). If the input factors are outputs from other production processes, then we get a three structure with several levels (Figure A.2). Outputs from intermediate production are sometimes from independent factories, but can also belong to the company that delivers a product higher in the three structures. If the intermediate product in a production tree is the final product from some factory, then we may split such threes in several smaller threes (Figure A.3). Even if we get rid of some nests in this way, there is still need for nested CES functions in production trees with intermediate products. But in order to implement nested CES functions it is of some help to consider the intermediate product as a final product, which make it possible to split these trees as well.

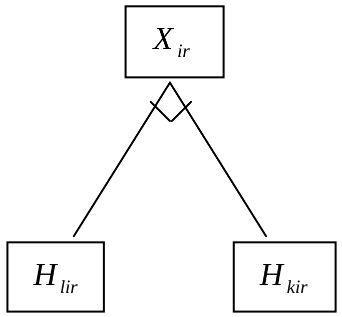

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Figure A.1. With a one level CES function, we may calculate the production X_{ir} as a function of two or more input factors H_{kir} and H_{lir} .

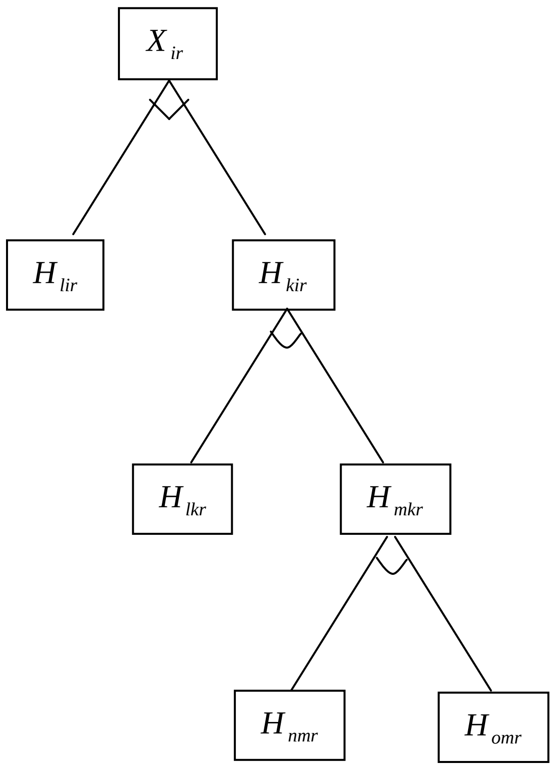

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Figure A.2 Nested CES functions makes it possible to calculate the production X_{ir} when there are intermediate products H_{kir} and H_{mkr} .

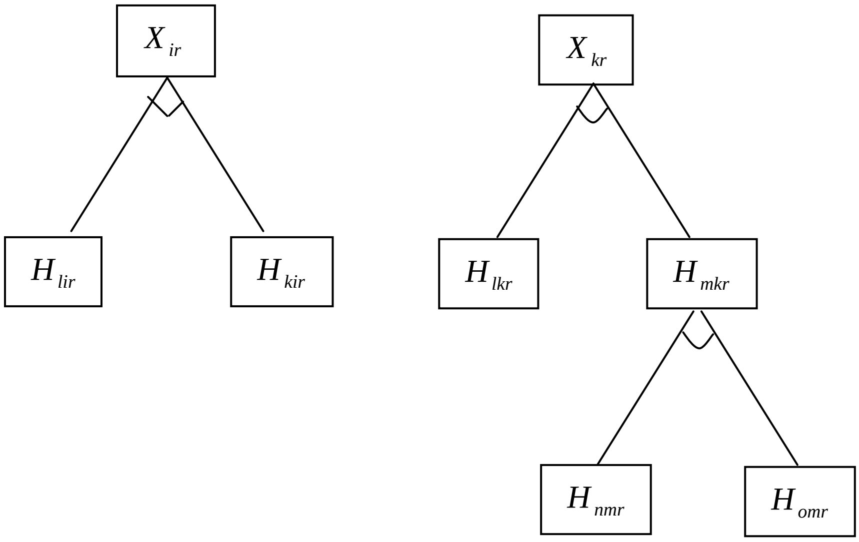

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Figure A.3. The whole or parts of the final product X_{kr} from a production three is used as an input factor H_{kir} in a different production three.

Appendix 2: An example

To investigate the nature of CGE modeling, we programmed a very stylistic CGE model in both the C programming language and the MPSGE software, with two production sectors (food and primary factors) (Figure A.2.1), and a sector for consumption of food and sale of labor to the production sectors. The producer of primary factors delivers commodities to the food producer. When there are two independent producers, then these may represent separate production threes (see Appendix 1). This simple example, allow us to represent production sectors with the usual non-nested CES functions (Figure A.2.2).

We used the SAM:

	Food	Primary factors	Consumption
Food	20		-20
Primary factors	-6	6	
Fuel		-1	1
Labor	-14	-5	19

We assumed that all unit costs are 1.0 in the benchmark situation, that the price of fuel is fixed and that the use of labor is constant, i.e., full employment with constant work force productivity.

We let X_1, X_2, X_3 and X_4 denote food, labor for production of food, primary factors, fuel and labor for production of primary products. The prices of these commodities are denoted P_1, P_2, P_3, P_4 and P_5. Consumption of food is set equal to the production of food whereas all other commodities only are used as input factors. Since the price of fuel is fixed and labor is constant, we have that $X_2 = X_{2,fixed}$, $X_5 = X_{5,fixed}$ and $P_4 = P_{4,fixed}$. If we use equations in Appendix 1 for Cobb-Douglas product functions on this case, with the price of fuel as a numeraire, then the model can be expressed in terms of the system of equations:

$$F_1 = C_1(X_1) - f(X_2, X_3) = 0$$

$$F_2 = X_2 - X_{2,fixed} = 0$$

$$F_3 = H_3 - f(X_4, X_5) = 0$$

$$F_4 = H_4 - X_4 = 0$$

$$F_5 = X_5 - X_{5,fixed} = 0$$

$$F_6 = \sum_k [P_k \cdot H_{k1}] - P_1 \cdot X_1 = 0$$

$$F_7 = P_2 - \gamma_1 \cdot \frac{1}{H_{2,1}} \cdot \alpha_{2,1} \cdot H_{2,1}^{\alpha_{2,1}} \cdot H_{3,1}^{\alpha_{3,1}} = 0$$

$$F_8 = \sum_k \left[P_k \cdot H_{k,3}\right] - P_3 \cdot X_3 = 0$$

$$F_9 = P_4 - P_{4,\,fixed} = 0$$

$$F_{10} = P_5 - \gamma_3 \cdot \frac{1}{H_{5,3}} \cdot \alpha_{5,3} \cdot H_{5,3}^{\alpha_{5,3}} \cdot H_{4,3}^{\alpha_{4,3}} = 0$$

We may formulate the system of equations as $\mathbf{F}(\mathbf{P},\mathbf{X}) = \mathbf{0}$. Since **F** is usually homogeneous of degree zero (for instance if we use CES production functions) in **P**, it is necessary to have an additional constraint in order to make it possible to determine the system of equations (Judd, s.188, 1998). According to Walras we have that sufficient conditions for equilibrium is $\mathbf{p} \cdot \mathbf{F}(\mathbf{p}) = \mathbf{0}$, and that $\mathbf{F}(\mathbf{p}) \leq 0$, $\mathbf{p} \geq 0$ (Lancaster, 1968). According to Judd (1998) the necessary extra constraint that follows from Walras law may be expressed by an extra equation $\sum_i P_i = 1$, from which we can see that prices are relative. With this extra equation, we get a system of equations where the number of equations and unknowns are the same.

Our system of equations becomes non-linear and can be solved with Newton's method. The method assesses production and prices in all iterations. This is done in two steps: First we have that cost functions are calculated for a given set of prices **P**, and thereafter we have that the elements in the right side of equation (4.16) for prices **P** and commodity volumes **X**. The left side is then determined such that the production of commodities in the county and import from other counties equals the right side. This way of adjusting the prices is referred to as Walras theory of tatonnement, and the solution we get is denoted as general equilibrium. If we alternatively allow profit, then we may ignore Walras law, but we must then assume decreasing return to scale of the production.

If we change the price of fuel to 1.4 times the fuel in the benchmark situation, then we get a decrease in production, where fuel is used as input (Table A.2.1).

The C program and the MPSGE program gave the same results.

Table A.2.1.Commodity volumes and prices for our stylistic equilibrium model in the benchmark situation and after a 40% increase in the fixed price of fuel

	Benchmark		40 % increase in the fixed price of fuel	
	Volume	**Price**	**Volume**	**Price**
Food	20	1	19.496	1.0
Lab_{mat}	14	1	14.0	0.9748
Primary	6	1	5.1196	1.0613
Fuel	1	1	0.6005	1.4
Lab_{prim}	5	1	5.0	0.9185

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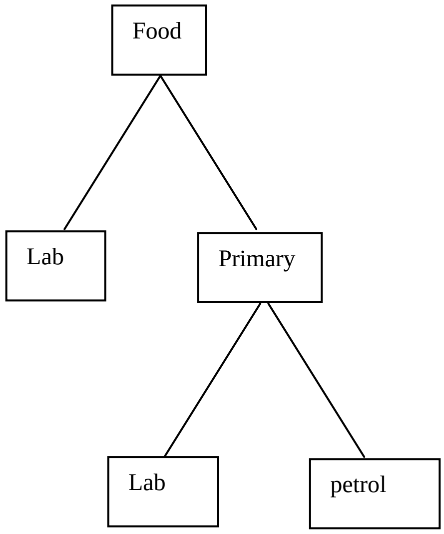

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Figure A.2.1. Stylistic production three for a food producer, where the commodities from a producer of primary factors are used as inputs.

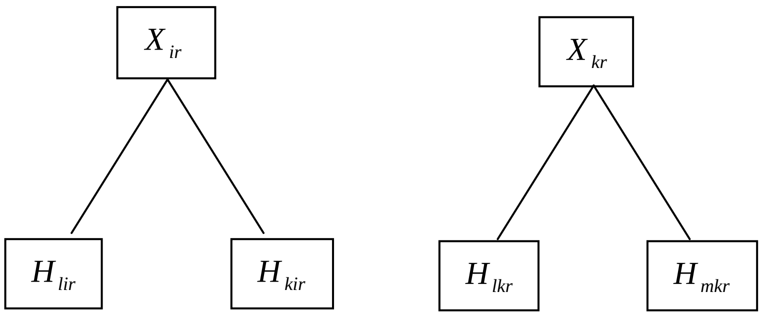

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Figure A.2.2. The same food producing sector as in Figure 5.1, where the commodities from a producer of primary factors are one input, but where the production three is split in one part for each production sector.